A REPORT ON AN INCREASED WATER SUPPLY FOR THE CITY OF SOUTH BEND, INDIANA

BY

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I hereby recommend that the thesis of CHARLES BAKER BURDICK entitled A Report on an Increased Water Supply for the City of South Bend, Indiana, be accepted as fulfilling this part of the requirements for the degree of Civil Engineer.

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TABLE OF CONTENTS

PART I

PART II

PART III

PART IV

LIST OF TABLES.

LIST OF EXHIBITS (Appendix)

A REPORT ON
INCREASED WATER SUPPLY FOR THE CITY OF
SOUTH BEND, INDIANA.

This report is made for the purpose of disclosing the best means for the increase of the South Bend municipal water supply taking into consideration the large investment in the existing works and all the circumstances that surround it. To this end a personal examination was made by the writer covering a period of about one week, supplemented by numerous surveys, tests and the abstraction of considerable data from the records of the water department, through an assistant working under his direction. The data thus secured were further supplemented by all the published information that could be found relating to the local geology. Most of the information relating to the geology within the city was gained through wells and borings previously made by the water department, or by citizens, the data of which had not previously been correlated.

Inasmuch as the needed investments for good service at this time require a somewhat large investment it was thought desirable to give some consideration to new and different supply sources, but the consideration of such new sources has been limited to showing clearly that there is no apparent reason strong enough to warrant a radical change in source - that a large investment can be made with assurance of permanence.

The principal conclusions resulting from this study are as follows:

1st. That the present source of supply, namely the water-bearing gravels underlying the city, is adequate not only for the present but for the distant future, and that it is the best source and the cheapest source available at South Bend.

2nd. That improvements should be planned with a view to accommodating a population of 75,000 within ten years, and 110,000 within twenty years. It is only by the anticipation of future growth that good service can be continuously maintained.

3rd. That the present average daily pumpage of about 4½ million gallons will be increased to 6½ million by 1920, and 9½ million in 1930; that average rates for twenty-four hours at about double these rates may be expected, and for short periods on summer days, three times these rates.

Further, that good fire protection requires the ability at any time to furnish water at rates about four times the annual average pumping rate, including the domestic use.

4th. That the extremely variable rates of pumpage can be most economically met by a storage reservoir at the pumping station, and that such reservoir will be effective in reducing the maximum rate of draft from the wells to an amount about double the average annual pumpage rate, permitting the wells at the North Station to operate at a maximum rate of not to exceed 6 to 10 million gallons per day during the next ten years.

It is concluded that elevated storage, namely, an additional standpipe, is not wise from either the standpoint of service or economy, and that, therefore, pump capacity should be available to meet the maximum rate of draft, with a reasonable reserve capacity.

5th. It is concluded, in view of the extremely low cost of pumping by water power, that the Central Station be maintained.

It is recommended that the wells at this station be improved after developments at the North Station, hereinafter mentioned, have been carried out.

6th. It is concluded that future developments of ground water should be confined to the low ground adjacent to the St. Joseph River. Developments at such location are far more economical than is possible upon high ground, unless extensive beds of much coarser material, and highly water bearing, are located elsewhere. Although all drillings made in South Bend, of which record could be obtained, have been examined, there is no indication of a locality more favorable for development than the St. Joseph River Flats.

7th. It is estimated that the cost of improving the North Station in such manner as to be capable of meeting good service requirements for the next ten years, is $140,800.00, with additional betterments from time to time as the service grows, entailing a total investment by the year 1930, of about $243,100.00.

8th. It is concluded that it is practicable to develop all the water needed by the city at this station for the next twenty years, at least.

9th. The borings and test wells at Portage Park, about one mile below the North Station, indicate that a station can be constructed at this site, of substantially the same capacity that is practicable at Leeper Park, the site of the present North Station.

The estimated expenditure required to construct a plant, substantially equal to the improved North Station, will amount to $237,380.00, in order to meet the service of the next ten years, and by 1930 the total investment in this plant will approximate $394,680.00, including mains for the delivery of the water into the city.

There will be a saving in the operating expenses of the Portage Park station amounting to from $1,000.00 to $2,000.00 per annum during the next twenty years, but this saving is more than offset by the fixed charges upon the additional investment required for the same service at Portage Park, as compared to an improved North Station.

The comparative figures for the present service are approximately as follows, exclusive of land: -

	Investment.	Operating Expenses Per Annum.	Fixed Charges Per Annum.	Total Annual Cost.
Improved North Station,	$140,800.	$13,280.	$9,640.	$22,920
Portage Park Station,	237,380.	12,300.	15,360.	27,660.

By the year 1930, based on the past rate of increase in population and pumpage, additional investments will have been required at these two sites, as follows:-

	Investment.	Operating Expenses Per Annum.	Fixed Charges Per Annum	Total Annual Cost.
Improved North Station,	$243,100.	$25,300.	$16.840.	$42,140.
Portage Park Station,	394,680.	23,100.	25,870.	48,980.

These estimates indicate that there is a financial advantage, all things considered, of from $4,000. to $7,000. per year in favor of improving the North Station, as compared to the construction of a new station at Portage Park. The reason for this difference lies in the ability to make use of investments already made at the North Station, and, of more importance, the proximity of the North Station to the center of distribution, obviating investments in a long discharge main. It is extremely rare to find a ground water supply so situated that it can be developed in the very heart of the distribution system, and it is only practicable at South Bend on account of the clay blanket that protects the water-bearing gravels from pollution. Many cities are forced to develop distant supply sources, but no such thing is necessary at South Bend.

10th. It is practicable to develop at the site of the North Station almost any quantity of water desired by the use of deep well pumps, and there is no question but that the use of such pumps in sufficient number would obviate the investment recommended in a storage reservoir. The initial investment in such a system of pumping would probably be less than in the reservoir. The operation of such pumps would only be necessary at times of maximum consumption, and therefore the power cost of such pumping would not be large in the aggregate for the present service. It is believed, however, and it is based on considerable experience with deep well pumping devices, that the fixed charges, interest and depreciation upon machinery of this type will materially exceed the fixed charges on a reinforced concrete reservoir, without considering the cost of power necessary to operate the machinery. It is concluded, therefore, that no radical departure in the means of operating the North Station is desirable, except the construction of the storage reservoir, and the means for keeping it filled with water.

11th. There is hereinafter outlined in some detail, the means by which the North Station can be modified to meet the present and future service. The details of this scheme, particularly as regards the number, kind, and capacity of the pumping units, and their arrangement and connection, should be subject to the further study of the designing engineer in the preparation of working plans. The total expenditure that is regarded as necessary to good service for the present and immediate future, is as follows:

Improvements at the North Station,	$140,800.
Reinforcements to the Distribution System,	30,000.
Total, - - - -	$170,800.

For the data upon which these conclusions are based, the studies relating to the source of the water supply, and a fuller statement of the reasons for these recommendations, the reader is referred to the following pages.

P A R T   II.

T H E   P R E S E N T   P L A N T,

ITS SERVICE, DEFECTS, AND DESIRABLE PROVISIONS FOR THE FUTURE.

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The city of South Bend is supplied from two pumping stations, namely the Central Station, located at the dam closely adjoining the business district on the east, and the North Pumping Station, located in Leeper Park, about half a dozen squares north of the business district and on the bottom land that adjoins the river below the dam. At both stations the water supply is obtained from a stratum of coarse sand and gravel, 30 to 40 feet in thickness, immediately overlying the shale bed rock. This water bearing sand is overlaid by a thick stratum of clay, which serves to protect the ground water in the immediate vicinity of the wells from local pollution, and also serves as a cover, through the agency of which the so-called artesian pressure is made effective, the water rising to about ground level at the Central Station, and about 10 feet above the ground surface at the North Station.

CENTRAL STATION:

The water supply at the Central Station is drawn from a system of 36 driven wells, 29 of which were in operation at the time of this examination. These wells are from 98 to 116 feet in depth, and range from 4 inches to 10 inches in diameter.

Normally the water is "sucked" directly from the wells by means of two Stilwell-Bierce power pumps; normal capacity 2½ million gallons per twenty-four hours, each, and discharged directly into the city distribution system. These pumps are normally operated by one or more of three 54 inch New American water wheels. There is also, directly connected to the main line shaft, a 250 H.P. Hamilton-Corliss Condensing Engine, which is used to operate the pumps when the water power is deficient. This engine is also directly connected to a 20" x 36" double acting air compressor, through which the capacity of the wells can be greatly increased, in case of emergency, by the so-called "air-lift" connections thereto.

The air lift plant was installed during the present early summer. Steam is supplied by a 225 H.P. Babcock & Wilcox battery of boilers, at 80 to 100 lbs. pressure. A small reservoir (about 300,000 gals. capacity) receives the water from the wells when operated by air lift, and the main pumps draw their suction from this reservoir at such times.

A brick encased standpipe, 5 feet in diameter and about 225 feet high, is connected to the station delivery main. The capacity of the standpipe is so small (about 34,000 gallons) that it is of very little value for storage purposes. It is worth the cost of its maintenance, however, for its beneficial effect on the momentary variations of the pumpage, and, further, as a safety valve or relief valve for the pumps.

The water is normally delivered into the mains under a pressure of about 80 lbs. per square inch. Upon an alarm of fire the pressure is raised to about 97 lbs. The standpipe is of sufficient height to accommodate either of these pressures without the manipulation of valves. On account of the water power it is profitable to operate this station continuously. The station is manned by two shifts of two men each. This station is capable of furnishing about 3-1/4 million gallons per twenty-four hours by direct suction from the wells, and the delivery of the station can be increased to about 4-1/4 million gallons by the operation of the air lift as at present installed.

A plat of the station and wells is shown on Exhibit No.1.

NORTH STATION:

The north station, located in Leeper Park, consists of 46 wells, ranging from 6 inches to 10 inches in size, and 80 ft. to 102 ft. in depth. The water is drawn from the wells by suction, and discharged directly into the city distribution system by means of two compound condensing direct-acting steam pumping engines, having daily capacities of three million and six million gallons per twenty-four hours, respectively.

The water pressures at this station are approximately the same as at the Central Station, except for a slight difference in elevation in the pump house floors, the North Station being about 6 feet the lower.

Steam is furnished by one 300 H.P. battery of Babcock & Wilcox boilers, and one single 208 H.P. boiler of the same kind; normal steam pressure 100 lbs.

The North Station is operated intermittently whenever the water demanded by the city exceeds the then capacity at the Central Station. There are usually a few days each year when the station is not operated, and on the peak of the summer load it has been operated continuously, day and night, for several days. During the past year and a half the station was normally operated from nine to twenty hours per day, depending upon the season of the year.

During the year 1910, the total output of this station amounted to about 30% of the total city consumption, and during the previous year about 13%. At the present time the station is capable of supplying easily seven million gallons per twenty-four hours, and it can be forced to about a nine million gallon rate, although at this rate the vacuum on the well system is so high (20 to 24 inches) that the pumps "pound" to a dangerous degree through the incomplete filling of the pump chambers.

The station is manned by two shifts of two men each, with an extra helper during the day and an extra fireman during the summer season.

A plat of the North Station and wells is shown on Exhibit No.2.

HISTORY OF WATER WORKS:

A brief history of the water supply at South Bend is as follows:

The original plant, including the Central Station, standpipe, and a small part of the distribution system, was installed in 1873, the original source of supply being the river.

Shortly prior to 1886 ten wells were driven, and in 1886 fifteen more were added. The system of wells was further increased in 1891 by the addition of nine wells, and five additional wells were added in 1906.

Up to 1885 the water was pumped by three 1 million gallon Vergennes power pumps, driven by water power. In 1885 a three million gallon steam pump was added, and in 1890 a six million gallon steam pump.

In 1895, the North Station was built, and the large steam pumping engine and one boiler moved from the Central Station.

At this time a system of 30 - 6" wells were installed at the North Station by the American Well Works. These wells were supplemented by four additional wells in 1906, designated as the "Kersey wells," and in 1910, by twelve additional 10 inch wells, designated as the "Koontz wells." These wells were especially constructed for a deep well pumping engine of special design. They are very closely spaced, there being two rows of wells 6 feet apart, the wells in each row being 4 feet on centers; the whole battery of wells occupying a space of 120 square feet.

TABLE A.

SHOWING GROWTH OF SOUTH BEND WATER SUPPLY,

Year	Population	*Average Pumpage Mil.gals.	Average Maximum Month M.G.D.	Daily Consumption per capita	Number of Water Takers	Consumption per consumer per day-	Population per tap
1894	29,000	1.89		65			
1895							
1896							
1897	32,000	4.13	5.3	130	3,680	1,120	8.7
1898	34,000	4.87	7.	143	4,350	1,120	7.8
1899	35,000	5.70	8.4	163	4,730	1,200	7.4
1900	36,000	6.25	7.2	174	5,390	1,170	6.7
1901	38,000	5.2	6.25	137	5,850	890	6.5
1902	40,000	3.9	4.4	98	6,430	607	6.2
1903	42,000	2.82	4.8	67	6,920	404	6.0
1904	43,000	4.05	5.2	94	7,490	540	5.7
1905	45,000	4.4	5.2	98	8,390	525	5.4
1906	48,000	4.67	5.45	97			
1907	50,000	4.8	5.5	96			
1908	51,000	5.22	6.9	102	10,150	520	5.0
1909	52,000	4.37	5.63	84			
1910	54,000	4.73	7.3	88	11,300	420	4.8

* Pump records previous to 1906 not reliable.

About 1898, a new battery of water tube boilers was installed at the North Station, and about 1900, the three million gallon steam pump was moved from the Central Station and installed in the North Station.

In 1906, the Vergennes power pumps at the Central Station were replaced by the present Stilwell-Bierce pumps. At the present time practically all of the machinery that has been installed from time to time is in service, with the exception of the Vergennes pumps.

Table A shows the principal facts relating to the growth of the distribution system, population, number of consumers, and the pumpage from the year 1896 to the present time.

PRESENT PUMPAGE:

It is very material to this inquiry, to form as accurate an estimate as possible of the future pumpage, not only in its aggregate from year to year, but the fluctuations in rate from month to month, from day to day, and from hour to hour, for the ability of your stations to maintain good service is vitally affected by these variations, and while a water works system is capable of enlargement from time to time to meet the demands of the service, it is very much better to look ahead and provide for deficiencies in advance of their occurrence, rather than to experience the annoyance and loss due to defective service after the defects have made themselves evident.

The future can be most accurately estimated by a scrutiny of the past, and therefore the records of the pumpage are of importance.

PUMPAGE RECORDS:

Exhibit No.4 shows a diagrammatic record of the pumpage of the years 1907 to 1911, inclusive. The diagram indicates the average daily pumpage in each month at the Central Station, and also the aggregate of the two stations. The diagram shows that the yearly average for the city has varied only slightly during the past five years. The monthly average has varied from about 3½ to 7-1/4 million gallons per twenty-four hours, with no marked tendency during this period to increase.

Exhibit No.5 shows the rate of pumpage at the two stations in each day of July 1910, - a month of heavy pumpage. During this month the North Station operated from twelve to twenty-four hours per day, and during the month furnished a little less than half the total water consumption of the city, which averaged 7.3 million gallons per day. For the first two days in July the rate during the daylight hours approximated 12½ million gallons.

Exhibit No.6 shows the pumpage record for each day in February, 1911, - a month of minimum pumpage. During this month the Central Station furnished 87% of the water consumed. The North Station operated usually less than twelve hours per day, and at a rate of only from one to two million gallons when operating. This month is typical of the winter, early spring, and late fall.

Exhibit No.5 is typical of one to three months of the summer and early fall during especially dry seasons, the heavy pumpage being largly affected by lawn sprinkling.

POPULATION TO BE PROVIDED FOR:

Exhibit No.3 is a diagrammatic representation of the growth in population of South Bend, according to United States Census, from 1850 to date, with an approximate forecast of the future based upon the past growth.

The growth of the city has been remarkably uniform. There has been no boom and no depression of such magnitude as to make itself evident in the population statistics. The city doubtless owes its healthy growth to that of a number of now very large manufactories, but the aggregate of the men employed is supplemented by the large number of smaller manufacturing industries, sufficiently diversified, so that the city has not felt the periodical depressions noticeable in cities where one line of manufacture is largely followed. The present population and the estimate of the future for the next two generations, is as follows:

1910	54,000
1920	70,000 to 80,000
1930	110,000 " 115,000
1940	120,000 " 160,000
1950	160,000 " 225,000

FORECAST OF ANNUAL AVERAGE PUMPAGE:

The pumpage records prior to 1906, when the new power pumps were installed at the Central Station, are quite unreliable owing to the large slippage in the old pumps, and to a certain extent this is true of all pumpage records prior to 1904, at which time the first accurate slip test was made, and slippages in the machinery of from 24 to 55% were noted. Slip tests made during the investigation indicate that the present slippage does not exceed from 1 to 5% in the various machines, and it is believed that the records of the last five or six years are quite reliable.

The old records indicate an annual average pumpage ranging from two million gallons per day in 1894 to six million in 1900, dropping to three million in 1903, four million in 1904, and gradually increasing with the population to five million in 1908. During the past two years the pumpage has fallen off to about $4\frac{1}{2}$ million.

Since 1904 the per capita consumption has ranged from 94 to 102 gallons. The percentage of the services supplied by meter has ranged from 8% in 1905 to 18% in 1910. The use of water per service connection has gradually decreased for the past ten years, most largely due to the rapid increase in the number of service connections and the consequent distribution of the constant leakage losses among a larger number of water takers. At the present time there exists a water service for each 4.8 persons. This figure indicates that the use of city water is quite general in the homes of South Bend; in fact, it indicates that nearly all of the existing houses are supplied. The growth in pumpage hereafter will therefore be likely to keep pace very closely with the growth in population.

It is possible that the further introduction of meters and the rigid curtailment of waste will still further reduce the per capita consumption. It is believed, however, that in making estimates for the future it will not be wise to provide for a smaller consumption than about 90 gallons per capita, and this figure can only be attained by careful management. Upon this basis the average daily consumption will reach 7 million gallons in 1920, and 10 million gallons in 1930.

MAXIMUM PUMPAGE:

Reference has already been made to the high rates of pumpage during the days of maximum demand. In a distribution system, where there is practically no storage, the hourly variations during such maximum days are of great significance. The writer is aware of no records upon the hourly pumpage at South Bend except those made by Mr. A. J. Hammond, former City Engineer, during July 1908, and reported to the Board in December of that year. Exhibit No. 7 is a reproduction of a similar diagram contained in Mr. Hammond's report, and indicates that upon a day when the average pumpage was 8.2 million gallons, the maximum rate for about an hour reached 580,000 gallons, corresponding to about 14 million gallons per twenty-four hours.

Based upon the data of Mr. Hammond's diagram, viewed in connection with the probable future increases in the average pumpage, an estimate has been made (See Exhibit No. 3 A) of the probable average rates that will prevail during the future days of maximum pumpage, and although this estimate is by no means accurate, it is the best guide available to aid in capacity estimates of machinery, storage, reservoirs, etc.

This diagram also shows the past increase in pumpage, both average and maximum. It will be observed that the maximum pumpage as recorded has remained practically stationary for the past fourteen years. It is probable, however, that a proper allowance for the unknown slip previous to 1906, would indicate a gradual increase, in general conformity with the increase in the average pumpage.

It is true that the maximum rate of pumpage per capita has a tendency to decrease as cities grow, and, therefore, that the increase in the maximum pumpage will hardly, in the long run, keep pace with the increase in average pumpage. An examination of the data available, however, seems to indicate that the decrease per capita of the maximum will probably not be sufficiently great within the next generation to be worthy of consideration.

FIRE PROTECTION:

In addition to supplying the maximum domestic demand, a municipal water works must be capable of protecting the city against fire. This imposes a large additional tax upon the station capacity, especially in cities of small or moderate size. In the very large cities the water rate demanded for this purpose bears a lesser relation to the total pumpage.

The pumpage rate that should be available for fire protection is largely a matter of opinion. Large reserve capacities in water supply pumping machinery and pipes involve considerable cost, and there is evidently a balance between the desirable investment for this purpose and the beneficial effects of the fire protection in the reduction of fire losses. It is a matter not subject to actual analysis in any particular locality without great labor. It is safe to say, however, that the great majority of cities are lacking in the fire protection afforded by their water works, and where adequate protection is provided it has usually followed a demonstration through a serious fire loss.

Some detailed study has been given to this matter by several able engineers, the result of whose studies are in print, particularly the studies of Mr. John T. Fanning, C.E., Mr. John R. Freeman, C.E., Mr. J. Herbert Shedd, C.E., and Mr. Emil Kuichling, C.E. The latest of these studies was made by Mr. Kuichling, about ten years ago, in which he summarizes the previous data upon the subject, and, in addition, conducted a correspondence with a large number of municipal fire departments as to the amount of fire protection considered necessary. As a result of these studies it has been demonstrated that upon the average the amount of fire protection bears a relation to the population of the municipality, although not in direct proportion thereto.

The National Board of Fire Underwriters has devoted a large amount of attention to this subject, and has done much valuable work in promoting the fire-fighting facilities of cities through their Bureau of Inspection, Tests and Reports. In general, the Fire Underwriters are recommending substantially the figures of Kuichling, with an added allowance of about 50% to cover losses through sprinkler systems, leakages, etc. especially incident to a large fire. The allowance that should be made for fire protection at South Bend, according to these various authorities, based upon the present population and also the estimated population in 1920, is as follows:

	Present Population. 54,000	Population in 1920. 75,000.
Fanning,	3,500 Gals.per Min.	4,000 Gals.per Min.
Freeman, (Average)	4,300 " " "	5,500 " " "
Kuichling,	5,000 " " "	6,100 " " "
Board of Fire Underwriters,	7,500 " " "	-------------

It is concluded, that good fire protection lies somewhere between 4,000 and 7,000 gallons per minute at this time, corresponding to twenty-four hour pumpage rates of 5.7 to 10 million gallons.

PRESENT DEFECTIVE SERVICE:

One marked defect in the water works service at South Bend is the inability of the plant to meet the maximum water rate demand of the warm summer months. At this time the water supply and pumping facilities are inadequate to supply the present domestic consumers, leaving no margin for adequate fire protection. It would, of course, always be possible to get a large quantity of water under low pressure by shutting off the feeder mains supplying districts not using water for fire protection at the moment, but it is not a practicable thing to do this, and no city, under any circumstances, should be without a water supply, not only capable of taking care of all domestic requirements and those of good fire protection, but, in addition, it should be the policy to have in reserve a certain capacity for the near future requirements so that improvements can be made in advance, and continuous good service in nowise interrupted.

QUALITY OF THE WATER:

From the standpoint of health, the water at South Bend is one of the best that it has been the writer's privilege to examine. There is no evidence of pollution in any analyses of record. Exhibit No. 8 is a tabulation of all the analyses of the city water available at this time. The tabulation also includes analyses from various test wells, and, for purposes of comparison, there is shown an analysis of the water from the St. Joseph River, taken at Benton Harbor, it being the only analysis of river water available on short notice.

The hardness of the water is moderate for ground waters in the Central West. The time may come when the city will find it economical to soften this supply, but in all probability this will not be desired for many years in the future. There are a few municipal softening plants in this country, but they all deal with water very much harder than the water at South Bend.

Most ground waters are more or less impregnated with iron, especially at certain seasons of the year, and certain analyses of ground water at South Bend show amounts of iron, that, if continuously present, would doubtless be very objectionable. Insufficient analyses are available to pass an opinion upon the likelihood of resulting troubles from iron in the municipal supply and the ground water at other places in and adjacent to the city. The best test of the water in this respect has been the municipal use of this water for over twenty-five years, without serious inconvenience.

There are certain ground waters containing iron that seem to permit the growth of a very objectionable vegetable organism, producing disagreeable tastes and odors, and clogging small openings in the distribution system. From inquiry at South Bend, it is understood that no objectionable tastes or odors have been generally noted, and that trouble from this organic growth has been absent, or present only in a very small degree.

The last analyses made show a total absence of iron at the present stations. Previous analyses seem to indicate that it has been present at times in large amount, and probably will be again. In a general way, waters that contain from .03 to .05 parts per hundred thousand of iron are frequently subject to the growth of the objectionable iron organisms.

INCOME AND OPERATING EXPENSES.

SOUTH BEND WATER WORKS

	Year 1909			Year- 1910		
Gross Receipts,			$92,500.86			$103,584.76
Operating Expenses, and Maintenance,						
Supt. Clerk, Assistants, Office, etc.		$14,226.93			$9,680.31	
Distribution of water, mains, meters, etc.		7,618.79			8,516.54	
Stable,		392.06			522.55	
Water sources, repairs, well, etc.		951.09			1,055.21	
North Pumping Station:						
Engineers & firemen	$3,605.75			$3,950.90		
Labor,	710.98			1,059.85		
Fuel,	4,916.29			7,555.58		
Repairs,	550.35			432.99		
Other expense,	235.30	10,018.67		385.66	13,384.98	
Central Pumping Station:						
Engineers & Firemen,	2,691.10			2,811.20		
Labor,	219.91			562.40		
Fuel,	198.15			1,313.52		
Repairs,	337.76			532.75		
Other Expense	338.99	3,785.91		427.25	5,647.12	
Tools, taps, stock, etc.		2,027.29			6,519.22	
			$39.020.74			$45,325.93
Pumpage Average per day:						
North Station (million Gals.)	.57				1.34	
Central " " "	3.80				3.39	
Total,	4.37				4.73	

P A R T III.

ADEQUACY OF THE PRESENT SUPPLY SOURCE, AND DESIRABILITY OF ITS RETENTION.

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The ground water supply at South Bend has impressed every one examining it, with its volume and the likelihood of its permanence. So far as known, no one has traced it to its source except in a general way. In the investment of so large a sum of money as is necessary for the water supply of this city, it is of importance to obtain as definite information as possible as to the permanency and amount of this water, and to make such estimates, it is obviously necessary to locate the source, and ascertain, as best we may, the transmission vehicle through which the supply passes from source to pumping station. In the investigation of a subject of this kind, we are dealing with matters more or less obscure. Approximately exact conditions can only be obtained at large expense, and although moderate investments in such investigations are wise, the conclusions must be largely reached on circumstantial evidence by taking advantage of the physical facts that have been determined from time to time by others.

In this investigation there has been collected and tabulated the record of all drillings that could be found in and adjacent to South Bend, including the municipal wells, a number of test wells recently drilled by the city, and the logs of such other wells as could be obtained. Part of this information is based upon the memory of those most familiar with the conditions. The greater part of the information, however, is obtained from memoranda made at the time the work was done.

At the more important places, particularly adjacent to the pumping stations and in the localities where future pumping developments have been contemplated, the writer caused levels to be taken by the City Engineering Department, and has made measurements of the water levels. In the more remote parts of the city the datum levels have been referred to the nearest street grades, and in some cases the water levels in reference to the surface/ are based upon statements of those familiar with the wells. A record of these drillings is shown on Exhibit No. 21, and the location of the drillings by number is shown on Exhibit No. 14.

Aside from a cursory inspection of the ground, the information as to the local geology is derived from numerous publications of the United States Geological Survey and the State Geological Survey. Those readers sufficiently interested to pursue this matter further than is possible in this report, are referred to the following publications:

U.S. Geol. Survey, Water Supply Paper No. 254. "The Underground Waters of North Central Indiana," by Stephen R. Capps, 1910.

U. S. Geol. Survey, Water Supply Paper No. 21. "Wells of Northern Indiana," by Leverett, 1899.

Considerable miscellaneous information is also to be found in U. S. Geol. Survey Water Supply Paper No. 31, the 38th Annual Report of the U. S. Geol. Survey; also a large number of Government publications dealing with the hydro-geology of the States adjoining Indiana.

GROUND WATER IN GENERAL.

It will aid in an understanding of the discussion which follows, to briefly review the sources of water supply, particularly ground water, and the nature of its occurrence.

The source of all water supply is rainfall. A part of the rain flows off over the surface through the watercourses, a part is absorbed by vegetation, a portion is re-evaporated, and a portion sinks into the ground where under most conditions it slowly travels toward the nearest watercourse, reappearing in the streams through seepage in the beds of rivers and lakes, or through springs where conditions are favorable.

The water may be collected for domestic use at any place in its travel, and our municipal plants draw upon it at all these places of its occurrence, depending upon the relative cost of securing good water from the particular source locally available.

The water, of course, differs much in its quality in these various places. The surface water is more or less polluted through human agency. The ground water is much less likely to be polluted, but in its travel through the soil it absorbs mineral matters, promoting hardness, and some ground waters are unfit for use owing to the quantity of dissolved mineral matters.

The ground water may penetrate to great depths, and there are many municipalities that obtain their supply from the seepage water in the rock, 1,500 to 2,000 feet below the ground surface. Excellent water supplies of this kind are found in Illinois and Wisconsin in the highly water bearing sandstones.

The deep underlying rock formations have been very well studied in Indiana, Michigan, and Illinois, and there is no likelihood that water of good quality can be obtained below the shale in the vicinity of South Bend. There have been several demonstrations of this fact in your immediate locality. The rock waters, where found, are highly mineralized, particularly with salt, making the use of the water impossible for domestic purposes.

It is, therefore, on the sands and gravels of the glacial drift that South Bend must rely for a supply of ground water.

THE GLACIAL DRIFT:

There is much of value to water supply in the studies that have been made of the great glaciers that covered this locality, and extended south as far as the Ohio River. They were probably formed when a very cold climate prevailed, in much the same manner as the present glaciers in Greenland, through the accumulation of snow to tremendous depths, and its packing, due to pressure. At this time the rocks were thinly covered with soil, and the accumulation of surface material now overlying bed rock, - amounting to 200 or 300 feet in thickness in St. Joseph County, - were formed by the rubbing action of these great glaciers as they passed over the rock surface. The material formed under the glacier is designated by geologists as "till", and is a mixture of stones and clay, intermixed by great pressure. It is very widely distributed in the glacial region, and usually overlies the rock.

As the edges of the glaciers moved forward into a warmer climate a melting of the ice took place, and the imbedded stones and miscellaneous detritus were deposited. There are indications that the edges of the glaciers remained practically stationary for long periods, the ice melting away as fast as it moved forward, and at these places were formed great hillocks of miscellaneous drift material, imperfectly stratified. These ridges are called "moraines."

The melting of these glaciers, going on probably more or less all the time from underneath, and particularly during the recession of the glaciers when the climate was becoming warmer, formed streams underneath the ice, and outside of the glaciated area. These streams brought down great quantities of sand, gravel, and boulder clay, and deposited these materials in horizontal strata, separating out the coarse gravel, the sand, and the clay, the former being deposited only in the swiftest water, and the clay where the water was slow. The materials thus deposited are designated as "alluvium". The alluvium has doubtless been greatly added to by the subsequent flow of the rivers since glacial times.

A fourth class of glacial formation is the "outwash" from under the edge of the glaciers, where the same occurred without well-defined water channels. In these so-called "outwash aprons" the materials are more or less stratified, although usually not horizontal.

These classifications of the drift are of considerable significance in the drift ground water supply, for the reason that the ability of these materials to absorb and transmit water is quite variable. The till is largely quite impervious, although it sometimes contains pockets of sand and gravel of considerable area, and is often locally available for farm wells. Municipal supplies can usually be obtained only in the moraines or outwash, or more particularly in the alluvium bordering these materials, and this is doubtless the source of the water supply at South Bend.

Exhibit No.9 shows a map of the glacial drift in the State of Indiana. The prominent features as regards water supply, are the moraines, particularly in the Northern part of the State, adjacent to which, on low ground, water can be obtained under head.

Exhibit No.10 is a glacial map of St. Joseph County, showing the distribution and kind of the glacial materials.

The area of St. Joseph County is about 460 square miles. The surface distribution of the glacial material is approximately as follows:

Till,	24%,
Outwash,	7%,
Moraine,	24%,
Alluvium,	45%.

About three-fourths of the county is therefore underlaid with materials ranging from slightly pervious to highly pervious; nearly one-half of the county consisting of stratified alluvial deposits containing much sand and gravel.

SOURCE OF SOUTH BEND SUPPLY:

Exhibit No.11 is a profile, platted to scale, showing the results of wells and borings along a line extending, roughly, southwest from the vicinity of Portage Park to the vicinity of La Salle or Beck Lake. It shows the static water levels, and the nature and thickness of the materials penetrated in drilling. Exhibit No.12 is a similar section extending south from the North Pumping Station. Exhibit No.13 is a section parallel to the general course of the river in the river valley.

These sections indicate a strong flow of water from the high ground south, southwest, and west of the city. The evidence is also circumstantial of a greater or less flow from the north, although very little data is obtainable of deep drillings north of the river. Such data as exists points to conditions similar to those to the south of the city.

From similar conditions elsewhere, in first taking up this problem it was thought likely that a strong flow would be found parallel with the river in the coarse alluvium, probably drawing supplies from the moraines and outwash for a considerable distance up the river.

The evidence seems to indicate, however, that there is a break in the pervious alluvial deposit in the eastern part of the city, at least that if the deposit is continuous, it swings to the south of the present river channel. The evidence on this point is, First, the decline in the static water level southwestward from North Station, and, Second, the poor water bearing materials found in the city test well in La Salle Park (boring No.8), in which clay was found to immediately overlie the shale, - a condition found nowhere else to the westward. - also the unsuccessful wells in Mishawaka in the vicinity of the present water works, and the very high elevation of the shale at this place (See Exhibit No.13). The new Mishawaka water works wells, south-east from the present plant, disclosed a very different drift formation, with shale at 235 feet below South Bend datum, - a position 140 feet below the shale at the South Bend Central Station. This would seem to indicate the possibility that the position of the pre-glacial river was somewhere south of the present course, and it is possible that the South Bend water-bearing stratum may be connected to the alluvium upstream through pervious materials, considerably south of the present river channel, possibly even underlying the outwash apron, and possibly even the moraine lying south of the present stream.

Such a condition is possible, because there are several well-recognized glacial periods in this region. The evidence indicates that this region was visited by three separate periods of glaciation. The moraines, - the most marked glacial evidence, - belong to the latest, or "Wisconsin" period. The evidences of the earlier periods are largely eradicated or hidden, and it is quite possible that the pre-glacial river channel may be filled with such materials as to contribute largely to the present water supply at South Bend.

The evidence indicates that in a natural state the rainfall collected upon the high ground is reaching the present river probably largely at some point below South Bend, by percolation through the underlying sands and gravels.

<u>EFFECT OF LAKE KANKAKEE</u>:

The broad belt of the alluvium southwest of South Bend (See Exhibit No.10) owes its origin to the existence in late geological times of the so-called geological Lake Kankakee, which is supposed to have been formed by reason of the more rapid recession of the glacier in Illinois and Northeastern Indiana at a time when the then outlet through the Wabash River was blocked with ice. This resulted in the great sand deposit of the

Kankakee marsh. The northern end of this deposit not only doubtless serves as a gathering ground for the South Bend supply, but also probably as a transmission medium for the water collected upon the moraines.

THE CLAY BLANKET:

A very important feature of the local ground water supply is the clay blanket overlying the water-bearing stratum in the river bottoms, and extending back under the terraces or low bluffs closely adjoining the bottoms to a greater or less extent. This blanket is of particular significance, in preventing the local escape of the water, to the end that it rises upon the lowest ground as much as 10 feet above the surface, thus permitting its utilization at a small investment, and, further, in the protection that is afforded against the contamination of the local ground water by the inevitable pollution of the city sub-soil.

The clay blanket has been located in every boring in or adjacent to the river bottoms between the Central Station and St. Mary's. It is penetrated in a number of other wells on the river terrace. It appears to be lacking at the Y.M.C.A., and at the grounds of the Singer Manufacturing Company it is only 2 or 3 feet in thickness in the eastern part, and entirely lacking in wells drilled a few hundred feet west.

In nearly all of the wells investigated some clay strata were encountered, but there seems to be no good evidence that the strata are continuous or of very large extent. It is probable that there exists ample means for the transmission of the ground water from its source to its outlet. Were this not the case, the large absorption of the moraines would appear in numerous springs and flowing brooks, which seem to be almost entirely absent in this locality.

It is useful, in the consideration of this matter, to make some attempt at capacity computations, although accurate figures are not possible. There is, however, available some accurate data as to the limiting supply capacity of underground watersheds, and the transmitting capacity of sands and gravels of various kinds. Such calculations frequently show that the accomplishment of a desired purpose is wholly impracticable, or they may indicate that under the most unfavorable circumstances very large supplies can be obtained.

CAPACITY OF GATHERING GROUND:

Upon Exhibit No.10 we have enclosed by a dotted line, the surface area that is probably available for the collection of water developed, adjacent to the river, in South Bend. This watershed, in the absence of surveys, is approximately defined by the 50 ft. contours of the Geological Survey map; the information as to street grades in South Bend; a general inspection of the country; and the general drainage courses, as marked on the County map.

The area of the watershed so indicated is about 100 square miles, made up of the following surface materials:

	Square Miles, Percent of Total.	Character.
Till,	8	Slightly absorptive.
Outwash,	6	Highly "
Moraine,	38	" "
Alluvium,	48	" "
Total, - - - - -	100	

Except in the southwestern part of the watershed, the surface materials are adapted to the absorption of a very large part of the rainfall.

This conclusion, derived from the origin of the drift, is borne out by an inspection of the watershed. Adjoining the city on the north, south, and west, the moraines are very marked, the surface topography is very broken, and abounds in hills and depressions; some of these depressions, many acres in extent, without outlet for the surface drainage except through sub-soil percolation. The sub-soil evidently readily admits the rainfall, particularly in one instance noted, where a depression of this kind without surface drainage was completely covered with growing corn. A large number of similar, though smaller depressions, were noted over a large part of the area designated upon the map as "moraine". This region is marked by the general absence of surface drainage lines, ditches, brooks, and creeks. West of the city several of the deeper depressions are occupied by a chain of lakes, fed from sub-soil flow, that find their outlet southwesterly into the Kankakee marsh.

Some data exists as to the supplying capacity of sub-soil watersheds that will be useful in defining the probable limits of the watershed at South Bend.

The water supply of Brooklyn is largely derived from wells in the drift. Very careful studies of this supply were made by the Burr-Hering-Freeman Commission on the water supply of Greater New York. It was the conclusion that about 30% of the rainfall reaches the sub-soil and is available for the ground water supply by pumping plants, properly located.

A study of several small watersheds adjoining Philadelphia (upon which rainfall and run-off records have been kept over a long series of years) indicates that from 12 to 18% of the rainfall reaches the sub-soil.

Experience in the sand dunes of Holland, Europe, where the ground water is greatly prized, indicates that from 30 to 50% of the rainfall is, or can be, profitably collected from the sub-soil.

An examination of the ground water supply at Holland, Michigan (made by the writer), indicates that from 22 to 30% of the rainfall has been collected from the sub-soil watershed at one of the city pumping stations, and a similar investigation at Jeffersonville, Indiana, upon a plant that is known to use only part of the available sub-soil water, has, for a number of years, developed about 8% of the total rainfall on the watershed.

The conditions in Holland, Europe, and Brooklyn, N.Y., are reported as quite favorable for the collection of ground water; that is, the soil is quite porous. At Holland, Michigan, the soil is a sandy loam, underlaid by sand, less favorable in porosity than the moraine adjacent to South Bend. At Philadelphia and Jeffersonville the conditions are distinctly less favorable.

The annual rainfall at South Bend averages 35 inches, and ranges from 44 to 28 inches, based on the 15 years from 1894 to 1908. Upon the assumption that 20% of the rainfall reaches the subsoil, - a conservative estimate, - the gathering capacity of the watershed will range from 20 to 30 million gallons per day. The monthly variations, and, in fact, the yearly variations, will probably have but a slight effect upon the elevation of the ground water, especially near the outlet thereof, close to the St. Joseph river, for one foot in depth of sub-soil water over the entire watershed area is equivalent to a supply of 10 million gallons per day for a year, without replenishment.

In the writer's opinion, it must be concluded that as far as the gathering ground is concerned, it has the ability to collect all the water needed by South Bend for several generations.

<u>TRANSMISSION CAPACITY FROM GATHERING WATER</u>:

The storage in the gathering ground can, of course, only be available at water works sites adjacent to the river through the existence of sub-soil water passages sufficient in capacity to transmit the desired quantity of water. Through the investigations of Slichter and others in the flow of ground waters through sands and gravels, and the result of numerous investigations on the flow of water through filters, it is practicable, when the exact character of the sand is known, to make fairly accurate estimates of the resulting velocity through such materials. It has been demonstrated that, unlike the flow in pipes, the flow through granular materials varies in direct proportion to the head or slope which causes the flow. Neglecting the factor of temperature, which has a considerable effect on the flow of water through filters, the relation between velocity and slope is expressed by the formula,

$$V = K S ,$$

where,

V = Velocity of travel through the pores, in feet per day,

S = The slope of the water surface,

K = A coefficient, depending upon the character of the sub-soil materials.

Where the slope = 1; that is, 45°, a very steep slope occurring only close to the wells, the coefficient represents directly travel in feet per day. The following values of K are given in Turneaure & Russell's Treatise on Water Supply, as a result of the investigations of Lembke, Darcy, and Krober:

Sand and Gravel,	9,400,
Coarse Sand,	2,800,
Medium sand,	760,
Fine sand,	150.

Professor Slichter places the following values upon K, depending upon the effective size of sand as determined by sifting, for materials having a porosity of about 30%, which corresponds to most water-bearing sub-soil material:

Effective size in Millimeters.	K (Ft. per day)
.2	171
.3	384
.4	681
.5	1066
.8	2730
1.0	4260

TABLE B.

TABLE SHOWING EFFECTIVE SIZE OF WATER BEARING SANDS AT SOUTH BEND, INDIANA.

Locality	Including Stones: Effective Size Millimeters.	Including Stones: Uniformity Coefficient	Stones sifted out: Percent Stones larger than 1/6"	Stones sifted out: Effective Size Millimeters.	Stones sifted out: Uniformity Coefficient.
Leeper Park Test Well at 75'	.23	3.0	0		
" " " " " 75' to 100'	.34	2.3	0		
" " Fine sand above water bearing material	.12		0		
Koontz Wells	.49	3.0	45	.25	5.7
Portage Park 10" Test Well	.37	4.2	21	.35	2.5
Eckman St. Test Well	.49	8	43	.35	4
Mishawaka City Wells:					
Sample #1	.33	2.6	19	.35	3.6
" #2	1.32		55		

As bearing particularly upon the capacity of the wells, the writer collected such samples of the materials as were available at the time of his visit, and although a small sample gives only an imperfect idea of the nature of the materials underground, the several samples from the different sources indicate approximately what may be expected. The sifting of these several samples is shown in Table B, herewith appended, showing a range in the effective sizes of the water bearing materials of from .3 to .5 millimeters.

Observation of the ground water profiles at the North Pumping Station during the tests indicates that near that place the value of K is in the neighborhood of 2000.

Upon Exhibit No.14 the writer has marked the ground water contours as they have been approximately determined by the numerous borings examined. The approximate average length of the 35 ft. and the 50 ft. water contours is 5½ miles.
Assuming 40 ft. of water bearing material, and a slope equivalent to the fall in the distance between two contours, which averages about 2500 feet, the resulting velocity of flow and quantity of water being transmitted would be as follows; under several assumptions as to the character of the water-bearing materials:

Character of materials.	Travel in ft. per day.	Quantity in Mil.Gals.per day.
K = 2000 (At North Station)	12 ft.	54
Medium sand, (Lembke- K = 760)	4.5	20
Fine sand, (Lembke - K = 150)	.9	4

The above computations are made on the basis of 3% porosity.

It is probable that even in the so-called water-bearing strata the character of the materials varies from place to place. A very thin stratum of coarse gravel, free from sand, has a transmitting capacity many times in excess of even the very coarse sand. A bed of stones about 1/6 of an inch in size has a water capacity about fifty times as great as coarse sand. It will thus be seen that thin layers of coarse materials, more or less free from sand, have a large effect upon the average water capacity of a water-bearing stratum, and this probably accounts for the fact that the flow coefficient adjacent to the North Station somewhat exceeds what would be indicated by the result of analyzing small samples.

It is regarded as probable that the transmitting capacity of the sub-soils between the borders of the gathering ground and the St. Joseph river is fully equal to the absorption capacity of the watershed, and this conclusion is borne out by the fact that springs adjacent to the city upon high ground are few and small. A lack of transmission capacity would necessarily force this water to the surface.

What has been said above serves to confirm the impressions that have long prevailed, that there is sufficient ground water available at South Bend for several generations to come, and that investments can safely be made, with good assurance of permancy.

PART IV.

BEST METHOD OF IMPROVING AND INCREASING THE PRESENT SUPPLY.

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Before discussing the means for increasing the present supply, it will perhaps add to a clear understanding to state the underlying principles of the flow from wells in sand and gravel. This principle is also the same for wells in any granular material, including sandstone and limestone, where the water enters the well through minute openings.

The ground water is caused to enter the well by a depression in the water surface in the well, and the difference in level between the water in the well and the water in the ground is the head or force that produces the flow. This head is principally required to force the water through the sand adjacent to the well. With proper construction and maintenance there should be very little loss in entering the well itself. In an open well this head can be directly measured by noting the ground water level at some distance from the well and comparing it with the water surface in the well. In inclosed wells, pumped by suction, this direct measurement can not be made, but the same fact can be ascertained by the assistance of the vacuum gauge.

Owing to the nature of the flow through granular materials, which has been hereinbefore referred to, the water producing capacity of any particular well is directly proportional to the head induced thereon by pumping; that is, if we note the water level in a well before the pump is started and we find that lowering the water level in the well to the amount of 5 feet produces, say 100 gallons per minute, we are assured that 10 feet will produce 200 gallons per minute, and so on. This is exactly true of all usual relations between well diameter and capacity in water works construction. In considering very excessive capacities per well, a small correction for friction in the well tube must be made, but this is of little significance in the consideration of the South Bend supply.

This principle also applies to so-called artesian wells, as follows:

If in its natural state the water stands say 5 feet above the ground, and we find that the well will flow 100 gallons per minute if opened at the ground level, we may be assured that 200 gallons per minute may be obtained by pumping to a depth of 5 feet below the ground surface. Each well when being pumped or when flowing, affects the water level or static head in the ground for a certain distance in every direction from the well; that is, if a series of pipes were drilled into the water-bearing stratum at uniform intervals in any direction from the well, it would be found that close to the well the water level would be nearly the same as in the well, and the water level in the other pipes would be found to stand higher as the distance from the well increases, until a point is reached where the normal ground water level is not affected.

As a result of this condition, we find that a group of wells does not furnish the same quantity per well under a given draft or head that is found to be true for a single well. This is owing to the fact that the influence of each well is likely to more or less overlap the influence of its neighbors. Under most circumstances, to place wells so far apart that they would be entirely uninfluenced by their neighbors, would require such a large investment in suction pipes as to make it more economical to compromise and suffer more or less interference to take place. This interference in the wells almost always occurs where the group of wells taps a single continuous water-bearing stratum.

A second general principle is this; that if a group of wells depresses the ground water level, in the immediate vicinity of the group, a certain amount in furnishing a certain quantity of water, that so pumping the group of wells that the water level depresses to double the amount, the quantity of water secured from the group of wells will be doubled.

The general principle that capacity varies directly as the depression in the ground water surface in a single well or in a group of wells, is an important principle to keep in mind in the consideration of the problem at South Bend. The character as to fineness or coarseness of the sand or gravel does not affect the general principle stated. The nature of these materials, however, does vitally affect the amount of water that can be secured per foot of depression or draft.

To aid in estimating the writer has made certain tests upon the existing wells at both stations, and has further noted the results from a nunber of tests previously made. A comparison of the old tests and those made recently serves to prove that the conditions today are not materially different from those of many years ago, and a comparison of tests in the different localities is likewise instructive as bearing upon the desirable locations of pumping stations.

SPECIFIC CAPACITIES OF SINGLE WELLS:

Diagram No.17 shows the relative capacity of two of the first five 6 inch wells driven at the North Station in 1895. The tests were made immediately after drilling the wells. The other three wells were tested and the capacities fell between those hereon noted. The diagram also shows a test of the 10 inch well at the Portage Park water works site, made this year, and also a test of one pair of the new 10 inch "Koontz" wells at the North Station. A comparison of these tests indicates that there is no material difference in the water gathering capacity at Portage Park and at the North Station.

In regard to the "Koontz" wells, owing to the location of valves, it was impossible to test a single well, and the flow curve as platted represents the result of two wells, 4 feet apart, tested simultaneously. It is probable that a test from a single well would show a capacity somewhat greater than any of the other single tests, owing to the long coarse strainer used.

Exhibit No.17 A is a tabular summary of all the well tests showing the capacity per foot of draft. An examination of this table serves further to emphasize the uniformity of the water-bearing materials from Central Station to Portage Park.

STATION CAPACITY:

The pump tests at the North Station and Central Station are summarized in Exhibit No.16.

Exhibit No.19 illustrates the respective capacities of the North Station and the Central Station, and also shows the governing elevations, ground level, floor level, and static water level, all having a bearing upon the development of the water supply. All levels are platted in reference to South Bend city datum. It will be observed that at the North Station, owing to the low floor level, the pumps were capable of depressing the ground water level in the wells approximately to the datum line, thus securing water at the rate of about 9½ million gallons per day, while at the Central Station, where the floor level is nearly 7 feet higher, and the static water level about 5 feet lower, the pumps were able to secure a little over 3 million gallons per day; the water level being depressed to about +9 city datum.The depression of the water levels refers to the conditions in the wells. At both places the vacuum on the pumps was slightly greater owing to the necessary friction in the pipes. When the North Station was being pumped at the rate of about 9 million gallons per twenty-four hours, the water level in the wells averaged close to the datum line. The water level within the group of wells, as observed by closing off a single well, stood at about datum 11. The water level in the last test well, 500 feet west of the nearest well in operation, and about 750 feet west of the center of the group of wells being pumped, stood at elevation 18. All these levels should be compared with elevation 29.5 static ground water level observed when the station was shut down.

MEANS FOR INCREASING STATION CAPACITY:

There is no question but that the condition of the strainers in the wells at the North Station is such that the supply at this time is materially less than it should be. Exhibit No.19 shows that with the "Koontz" wells shut off the station is capable of producing only about $5\frac{1}{2}$ million gallons. Mr. Thomas Ayres, Superintendent, states that previous to 1905, these same wells could, and did, at times run both pumps at full rate, amounting to about 9 million gallons per day.

The test of the North Station at maximum capacity indicates that about 11 feet of head is required to force the water the last 100 feet toward and into the well. The average delivery per well during this test was about 140 gallons per minute. The numerous tests upon single wells when new indicate that only about 5 feet of head is required to deliver the same quantity of water.

Mr. A. J. Hammond, former City Engineer, in his Report to the Board, printed in the Annual Report of 1908, mentions the clogged condition of the strainers at the Central Station, and gives a test showing the beneficial effect of cleaning the strainers. A similar result is mentioned in the Annual Report of 1904, in which 30 wells at the North Station were cleaned by the American Well Works.

It is concluded that with good strainers, well maintained, the flow from the present system of old wells can be increased 30%.

It is probably too much to expect that any strainer will permanently operate without occasional removal and cleaning. It is of great advantage that the strainers be of considerable length, and coarse in mesh, and it is of vital importance that they be so constructed that they can be removed and replaced without destroying the well. The strainers of the original 30 six inch wells at the North Station are short - not exceeding 10 feet in length - have a very fine gauze mesh, and are screwed fast to the well casing. Although it may be possible to clean these wells by the use of compressed air or back-flushing, it is probable that these wells must be replaced before the full usefulness of the North Station is secured, and in the estimates of cost, hereinafter given, it has been assumed that practically all of these old wells on the mainland will be replaced with new wells. It is not advised that this be done, however, until the effect of cleaning is tried, and it is strongly urged that when this is done an intelligent test of each well before and after cleaning be made.

CONCLUSION AS TO ULTIMATE CAPACITY OF NORTH STATION:

It is concluded that the system of wells in Leeper Park can be so improved and extended as to produce from 12 to 15 million gallons per twenty-four hours without depressing the well water levels below "suction reach" from pumps located at substantially the present floor level. It is practicable to still further increase this capacity very materially by depressing the elevation of the pumps and suction pipes, or by the operation of deep well pumps, but the writer does not favor either of these methods. It is only with great difficulty and expense that deep suction pipes can be maintained air-tight, and the maintenance of the suction pipes in good condition is very important in developing this supply by direct suction.

THE EFFECT OF STORAGE:

As has been previously pointed out, the maximum consumption of the city is fully three times the average consumption, and the maximum pumpage rate at the North Station is more than six times the average pumpage rate. When fire protection is considered, these ratios are very materially greater.

When pumping directly from the wells to the distribution system, the capacity of every part of the plant is based upon the maximum rate of consumption even for a very short period. It would be of material advantage if the rates of pumpage could be made more uniform, and this can be accomplished by the storage of the water so that the supply can be fed from storage when the demand is at a maximum, and replenished when the demand is at a minimum.

It is not practicable to build a storage reservoir sufficiently large to be of effect on the seasonal variations in the pumping, but if the variations in the hourly rates of the maximum day could be eliminated the pump capacity for domestic service could be cut substantially in half, and material savings could be effected by eliminating the extreme variations for the maximum hours. This could be accomplished by a small amount of storage, and would be economical if the storage is not too costly.

It is evident that to be of any assistance to the pumping engines the storage must be elevated; that is, that the reservoir must be built upon high ground, or a large standpipe constructed preferably upon as high ground as can be obtained reasonably adjacent to the pipe system. The elimination of the heavy draft rates upon the wells can be largely accomplished by the construction of a reservoir on the ground level at the pumping station.

ELEVATED STORAGE:

There are many cities that utilize large storage reservoirs built upon adjacent high ground. These cities are very fortunately situated, because a uniform rate of pumpage can be maintained, but no such site is available at South Bend, and any elevated storage structure would necessarily be in the nature of a standpipe. The governing elevations in this matter are as follows; all levels being stated in reference to city datum:

Central Station,	24.7 ft.
North Station,	18.3 "
Top of Standpipe, (= 97 lbs.fire pressure)	255 "
(Equiv,of domestic press. 80#)	216 "
Level of over 90% of City,	50 to 60 "
Small area north east part,	80 to 85 "
Small area south part,	70 to 85 "
Small area south part, not yet piped,	90 to 120 "
Highest ground available for standpipe, 3000 feet south of Ewing Ave.,	173 "

It would therefore require a standpipe about 80 feet in height to be useful for elevated storage.

It has been proposed to construct a standpipe on this site, and to lay about 11,500 feet of 20 inch main, to connect it with the principal artery of the distribution system.

As bearing upon the needed capacity in storage to effect given results, reference is made to Exhibit No.7 which shows the hourly pumpage rates upon a maximum summer day. Upon this day the maximum rate was 14 million, or 583,000 gallons per hour. The effect of various storage capacities in reducing this hourly rate, based on this day, are as follows:

Maximum Pumpage Rate, with Storage. Mil. Gals.per 24 hrs.	Gals.per hr.	Volume of Storage in gallons.
14	583,000	0
12	500,000	161,000
11	460,000	310,000
10	417,000	527,000
9	375,000	853,000

The average pumped on this particular day was 8.2 million gallons. The standpipe proposed was 40 feet in diameter and 80 feet in height, containing a total capacity of 740,000 gallons, and containing 363,000 gallons above the domestic pressure line. It is estimated that the storage capacity above the domestic pressure line in this standpipe would have been effective upon the day of maximum consumption noted to the extent of reducing the maximum hourly pumpage rate by the amount of 3.2 million gallons; that is, it would have reduced the necessary pump capacity about 23%.

The estimated cost of the proposed standpipe was $18,700.00, and the cost of the 20 inch main (11,500 feet in length) about $44,000.00, making a total cost of $62,700.00 or allowing reasonable rates for interest and depreciation, a fixed charge of about $4,000.00 per annum. It is practicable to provide the same amount of storage at the ground level at the water works station, and pumping facilities sufficient to maintain the reduction in rate effected by the standpipe, at an expenditure of not to exceed $25,000.00, with fixed charges of less than $2,000.00 per annum. It is believed, therefore, that, from the standpoint of economy, this standpipe is not warranted. If built, it will involve the necessity of either suffering a material reduction in the city water pressures near the end of the storage period, or it will necessitate filling the standpipe to a point near the fire pressure level during the night, either of which contingencies would be undesirable from an operation standpoint. It would further make impossible the prompt raising of fire pressure unless a controlling valve were placed at the base of the standpipe, and if such valve were closed the beneficial effect of the storage would be lost. It is concluded that the water can be most profitably stored in surface reservoirs at the water works station.

GROUND LEVEL STORAGE:

A storage reservoir at the water works station will accomplish two important purposes. It will permit a uniform pumping rate at the North Station for the supply of domestic consumers, and, if sufficiently capacious, will store sufficient water so that a large conflagration can be extinguished at any rate of pumpage made possible by the pumping machinery, without regard to the supply from the wells. A reservoir of 5 million gallons capacity will contain sufficient water to make possible a uniform twenty-four hours' pumpage, and at the same time, reserve sufficient water to supply 5,000 gallons per minute, or 20 fire streams for a period of at least ten hours, assuming that the wells are pumped at such capacity as to supply the domestic consumers only.

A rectangular, box-type, reinforced concrete reservoir, is suggested, about 135 ft. x 250 ft. in plan. A good site for this reservoir exists southeast of the station, immediately east of the tennis courts. Judging from the borings - the report of which has been examined - the sub-soil conditions are particularly unfavorable for deep excavations, and it is tentatively suggested that the reservoir be constructed about half its depth in excavation. The estimates include a reinforced concrete cover, and, if desired, the reservoir can be covered over with earth and sodded. If not covered with earth, the reservoir can be made attractive, architecturally.

Some two or three years ago a suggestion was made to effect storage by the construction of a deep reservoir, into which the wells would discharge by gravity. On a site underlaid with impervious clay this plan, or a slight modification of it, would doubtless work out to great advantage. The writer is inclined to acquiesce in the Report of Mr. E. E. Brownell, made in 1909, that under the existing sub-soil conditions, such a scheme would be burdened with excessive cost and some considerable danger.

Based upon the pumpage rates forecasted on Exhibit No.3A, and the figures hereinbefore given as to desirable rates for fire protection, and also considering the effect of storage, the necessary station capacities for the next twenty years are as follows; all pumpage rates are expressed in million gallons per twenty-four hours:

	Present Time. Pop. 54,000.	1920 Pop.75,000.	1930 Pop.110,000.
Capacity of machinery,			
Domestic Maximum, 6 Hrs.	12½	17½	25
Capacity of Machinery,			
Fire Protection,	7½	9	11
Total capacity machinery,	20	26½	36
Capacity Central Station,			
deducted, - - - - - - - - - - -	4	4	4
Machinery, North Station,--	16	22½	32
Desirable contents of Storage,			
Domestic Purposes,	1	1½	2
Desirable contents of Storage,			
Fire protection,	3	4	5
Total contents storage,	4	5½	7
Total necessary capacity from			
Wells,	10	14	19
Capacity Central Station,			
deducted, - - - - - - - - - - -	4	4	4
Total necessary well capacity			
North Station, - - - - - -	6	10	15

It will thus be noted that the net effect of a $50,000. investment in storage will practically permit the existing well supply to furnish the necessary water for seven or eight years to come, providing the present well capacity suffers no further decrease. It is not to be expected, however, that such a fortunate circumstance is likely to exist, and the writer recommends the improvement of the present well system to the extent of correcting the existing excessive strainer losses; the strainer system to be so designed that it can be maintained in good condition.

GENERAL PLANS FOR IMPROVEMENT OF WORKS:

In order to form an intelligent idea as to the most economical means of supplying the city with water, now and hereafter, two of the more promising projects have been worked out in more or less detail. Further study by the designing engineer in the preparation of plans and specifications, will no doubt disclose modifications in the suggested plans, that can be profitably made, but it is believed, that the general decisions are sufficiently accurate for preliminary estimates and bases of comparison.

The plans will be considered in the following order: Plan No.1, - The Rehabilitation of the Existing Plant in Leeper Park (the North Station), and Plan No.2, - The Construction of a New Plant at Portage Park in the vicinity of Terrace Avenue and the River.

PLAN NO.1, - IMPROVEMENT OF NORTH STATION:

This plan, for sanitary reasons as formerly recommended, involves the abandonment of the wells upon the island adjoining the station, and the improvement of all, or nearly all, the existing old wells to the extent of renewing them entirely, if necessary: the construction of a small suction well at the pumping station: the construction of a 5 million gallon reservoir: the installation of two 5 million gallon, engine or turbine driven, low lift centrifugal pumps for filling the reservoir: a 10 million gallon high duty pumping engine, and the increase of the boiler plant by the addition of 250 Horse Power.

It is estimated that by the year 1920 the pumpage will have grown so that additional improvements will be necessary, as follows:

One 10 million gallon medium duty engine; an additional 250 Horse Power Boiler; an additional low lift pump, and about 9 additional wells, probably located to the southeastward of the existing group.

By about 1930 it will be necessary to add one 10 million gallon medium duty engine; two additional 250 Horse Power boilers; about 19 additional wells, located in the western half of Leeper Park; a further addition to the pumping station building, and also about 2½ million gallons additional water storage. The estimated cost of these improvements is shown on Table C, and the estimated operating costs, with fixed charges on the additional investment added, are shown in Table D.

TABLE C.

COST OF IMPROVING NORTH STATION.

Year 1912 - (Average pumpage 5 Million)		
1 - 10 million high duty engine,	$35,000.00	
2 - 5 " low lift centrifugals,	6,000.00	
1 - 250 H.P. boiler,	4,000.00	
Chimney(if necessary)	4,000.00	
Addition to building (for conditions of 1920)	14,000.00	
Improvement of present wells or additional wells,	12,000.00	
Rearrangement of suction and discharge piping,	3,000.00	
Reservoir,	50,000.00	
Contingencies and incidentals (10%)	12,800.00	$140,800.00
Year 1920 -		
1 - 10 million medium duty engine,	12,000.00	
1 - 250 H.P. boiler	4,000.00	
1 - 5 million low lift centrifugal,	3,000.00	
Additional wells and pipes,	7,000.00	
Contingencies and incidentals (10%)	2,600.00	28,600.00
Year 1930 -		
1 - 10 million medium duty engine,	12,000.00	
2 - 250 H.P. boilers,	8,000.00	
Addition to building,	7,000.00	
Addition to reservoir,	25,000.00	
Additional wells,	15,000.00	
Contingencies and incidentals (10%)	6,700.00	73,700.00
		$243,100.00

TABLE D.

OPERATING EXPENSE AND ANNUAL COST.
IMPROVED NORTH STATION.

	Old Station	Improved Station.		
	Year 1910.	1912	1920	1930
Station Operating Cost.				
Labor	$5,000.	$5,000.	$6,500.	$7,000.
*Fuel	7,555	4,680.	6,560.	9,470.
Repairs	433.	600.	900.	1,500.
Incidentals	386.	500.	800.	1,300.
Wells	1,055.	2,500.	3,500.	5,000.
	$14,429	$13,280.	$18,260.	$24,270.
Interest and depreciation on added Investment,		9,640.	11,810.	16,840.
TOTAL ANNUAL COST,		$22,920.	$30,070.	$41,110.
Principal Operation Details.				
Pumpage total average daily,	4.73	5.0	6.8	9.6
North Station	1.34	2.0	3.8	6.6
Coal tons per year	2629	1630	2280	3300
Station Coal duty (Millions)	15	37	50	63

*Fuel @ $2.87 per ton.

PLAN NO.2. - NEW STATION AT PORTAGE PARK:

In this plan the construction of a station is contemplated substantially as has been formerly proposed, with some slight modifications to make the project more easily comparable with an improvement at the North Station. In brief, the project involves the ultimate use of substantially all the land shown on Exhibit No. 15, partly owned and partly optioned by the city. The plant for present and near future conditions, includes substantially the same machinery and layout hereinbefore described at Leeper Park, and the moving of the existing steam machinery at the North Station. The estimate provides for a new boiler plant, although the old boilers might be profitably moved, depending upon their condition. The estimate also includes a 30 inch discharge main, about 6200 feet in length, connected to the present distribution system, about two blocks west of the North Station.

By the year 1920 it will be necessary to add substantially the same improvements contemplated at the North Station for that year. The same is true of the year 1930, at about which time it will be necessary to add an additional 30 inch discharge main. Table E shows the estimated cost of these improvements, and Table F is an estimate of the operating expenses with and without fixed charges.

TABLE E.

COST OF THE NEW STATION AT PORTAGE PARK.

Year 1912 -

1 - 10 Million high duty engine,	$35,000.00	
Moving two old pumps,	3,000.00	
2 - Low lift centrifugals,	6,000.00	
3 Boilers, 750 H.P.,	12,000.00	
Chimney,	4,000.00	
Pump House,	25,000.00	
Suction Well,	3,000.00	
Station pipes, valves and miscellaneous,	8,000.00	
Wells,	14,000.00	
Well pipes,	7,800.00	
Reservoir,	50,000.00	
30" Discharge main - 6200'	48,000.00	
Contingencies and Incidentals (10%)	21,580.00	
		$237,380.00

Year 1920 -

1 - 10 Million medium duty engine,	12,000.00	
1 - 5 " low lift centrifugal,	3,000.00	
1 - 250 H.P. Boiler,	4,000.00	
Additional wells and pipes,	7,000.00	
Contingencies and Incidentals (10%)	2,600.00	
		$28,600.00

Year 1930 -

1 - 10 Million medium duty engine,	12,000.00	
2 - Boilers, 500 H.P.,	8,000.00	
Addition to building,	7,000.00	
Addition to reservoir,	25,000.00	
Additional wells and pipes,	15,000.00	
Additional 30" force main, about	50,000.00	
Contingencies and Incidentals (10%)	11,700.00	
		$128,700.00
		$394,680.00

TABLE F.

OPERATING EXPENSE AND ANNUAL COST.

NEW STATION AT PORTAGE PARK.

	Old Station Year 1910.	1912	1920	New Station. 1930.
Station Operating Cost.				
Labor,	$5,000.	$5,000.	$6,500.	$7,000.
* Fuel,	7,555.	3,700.	5,200.	7,500.
Repairs,	433.	600.	900.	1,500.
Incidentals,	386	500.	800.	1,300.
Wells,	1,055	2,500.	3,500.	5,000.
	$14,429.	$12,300.	$16,900.	$22,300.
Interest and depreciation on added Investment, - -		15,360.	17,550.	25,870.
TOTAL ANNUAL COST, - - - -		$27,660.	$34,450.	$48,170.
Principal Operation Details.				
Pumpage total average daily,	4.73	5.0	6.8	9.6
Portage Station,	1.34	2.0	3.8	6.6
Coal tons per year,	2629	1630	2280	3300
Station Coal duty (Millions)	15	37	50	63

* Fuel @ 2.87 Old Station and $2.27 New Station.

COMPARISON OF PROJECTS:

Table G summarizes and compares the principal figures of cost, operation cost, and fixed charges on these two projects. One is led to the conclusion that, from a financial standpoint, the improvement of the North Station has the advantage over a station at Portage Park to the extent of from $4,000. to $7,000. per annum, which is equivalent to 5% interest on $80,000.00 to $140000.00, without considering cost of land, which is also in favor of the North Station.

The North Station further has the advantage of its proximity to the center of water supply, and the advantage of more than one delivery main, - an advantage that would not be enjoyed by the Portage Park site (except at great expense) for a number of years. The Portage Park station has a small advantage in the matter of its accessibility to switching facilities, making possible a saving of about 21% in the cost of fuel. This saving, however, amounts to only about $1000.00 per annum under the improved coal economy of a new station at Leeper Park, under conditions of 1912, and about $2200.00 per annum for conditions of 20 years hence, - sums equivalent to from one-quarter to one-half the fixed charges upon the pressure main between the two stations. Allowances for these items have been made in the comparison of annual costs, hereinbefore given. It is concluded that the best policy lies in the improvement of the North Station at Leeper Park.

TABLE G.

COMPARISON OF PROJECTS.
Nos. I and 2.

	Project No.1. Improved North Station.	Project No.2. New Station Portage Park.	Difference.
Investment in 1912	$140,800.	$237,380.	* $96,580.
" " 1920	169,400.	265,980.	* 96,580.
" " 1930	243,100.	394,680.	* 151,580.
Operating expense in 1912	13,280	12,300.	+ 980.
" " " 1920	18,260	16,900.	+ 1,360.
" " " 1930	24,270.	22,300.	+ 1,970.
Fixed Charges in 1912	9,640.	15,360.	* 5,720.
" " " 1920	11,810.	17,550	* 5,740
" " " 1930	16,840	25,870	* 9,030.
Total Annual Cost:			
Operation plus fixed charges in 1912,	22,920.	27,660.	* 4,740.
Operation plus fixed charges in 1920,	30,070.	34,450.	* 4,380.
Operation plus fixed charges in 1930,	41,110.	48,170.	* 7,060.

* In favor of North Station

\+ " " " Portage Park.

DEEP WELL PUMPING:

As has been hereinbefore mentioned, it is practicable to obtain almost any quantity of water desired at the North Station by deep well pumping. The writer has given considerable study to this method of procuring ground water, and has installed a number of plants, now in operation, under lifts up to 150 feet. This type of pumping apparatus is necessary under some circumstances, and there is machinery now upon the market that will accomplish results with a minimum in the way of maintenance and operation charges.

Some consideration has been given to this means of pumping at South Bend, particularly with a view to the occasional use of deep well pumps in tiding the plant over its maximums, and thus to obviate the considerable investment in a storage reservoir. This would involve deep well pump capacities of about 16 million gallons at the present time, and about 32 million gallons twenty years hence, and although the investment in deep well pumping apparatus would be somewhat less than the $50,000.00 investment in a reservoir to take care of present conditions, - perhaps two-thirds to three-quarters, considering alterations in wells and pipes, - the fixed charges upon apparatus of this kind are large as compared to the same charges on a reinforced concrete reservoir. It is believed that a low estimate of the fixed charges upon such apparatus would materially exceed the fixed charges upon the reservoir, without considering repairs or the power necessary to drive the deep well apparatus.

ELECTRIC PUMPING:

Consideration has further been given to the possible use of electricity at the North Station, under a contract similar to that previously drawn up for the Koontz deep well pumps, which provides for a flat motor H.P. charge of One Dollar per month and for current at the rate of 0.8 cents per K.W. hour. It is concluded that the pumping service at the North Station is, and will be for a long time to come, too variable to make the use of electricity profitable.

It is evident, from the rates of pumpage shown in this report, that the average consumption of current would be but a very small percent of the reserve capacity that must be constantly available for fire protection, - at the present time not to exceed eight percent. The time will probably come when it will be desirable to install a small pumping plant to operate continuously. At such time, it may be economical to install an electric pump at Portage Park, or some other convenient location somewhat distant from the North Station, discharging water at a uniform rate through a comparatively small pipe into the distribution system. Such use of electricity for continuous, or nearly continuous operation, would probably be profitable, but such an investment would not be warranted until the best use of the existing investment at North Station has been made to its fullest extent.

CONTINUED USE OF CENTRAL STATION:

A previous recommendation as to the desirability of permanently retaining the Central Station as a part of the water works, on account of the economy in operation practicable through the use of the water power is endorsed. It seems certain that the improvements at the North Station will demonstrate the practicability of considerably increasing the available flow from the wells, through the use of proper strainers, well maintained, and when such facts have been demonstrated, it is recommended that the Central Station wells, or as many of them as seems advisable, be similarly improved. It would be of considerable advantage to increase the capacity of this station, by direct suction, to $4\frac{1}{2}$ to 5 million gallons, and it can probably be accomplished by utilizing the street space adjacent to the station to obtain a somewhat better and more wide distribution of the wells. Care must be exercised, both here and at the Central Station, to obviate the possibility, wherever at all likely, of leakage from sewers or street wash entering the suction pipes. It is not possible that such leakage could enter the wells except through broken well casings, but leaks into the suction pipes are possible, and probable unless the sewers are removed from the vicinity of the suction mains.

THE DISTRIBUTION SYSTEM:

The available time has not permitted an examination of the distribution system, sufficiently in detail to make definite recommendations as to all desirable enlargements at this time, and to provide for the increased water consumption and fire protection of the future. The present system is sufficient to provide ample fire protection for the business district for the next ten years at least. Your Engineers, Messrs. Burns & McDonnell, and the Board of Fire Underwriters, who have lately examined the city in detail, are agreed as to the desirable location of certain needed mains to improve the fire protection in the manufacturing district, and to strengthen the pipe system near the borders of the distribution district.

It is believed all these extensions are warranted, particularly those strengthening the manufacturing district in the vicinity of the Studebaker Plant, the Oliver Plow Works, and the Singer Manufacturing Company. The estimated cost of these extensions is $30,000.00, exclusive of the cost of replacing paved street surfaces, if any such pavements are disturbed in the laying of these pipes. Owing to the location of these betterments, it is not likely that a large amount of pavement must be cut into.

In the not very distant future, it will be desirable to further strengthen the fire protection of the manufacturing districts by the extension of the large main in Washington Street, or preferably, if possible, connecting in a feeder at one of the streets paralleling same, west of Chapin Street, and as the city grows, the main arteries leading to the outskirts must, at intervals of ten years or so, be strengthened by feeders that can best be worked out in detail at the time they are needed, although there should be a general plan worked out for the future enlargement of the distribution system, so that the betterments can be made from time to time, largely as extensions are needed, by laying the feeder pipes of such size as to fit into the distribution system of the future.

USE OF PARK FOR WATER WORKS PURPOSES:

There should be no objection, aesthetically or otherwise, to the construction of a water works station in the public park of the city. The modern tendency in water works construction is to make the municipal pumping plant as attractive and as clean as a modern kitchen, and although the existing plant at Leeper Park is structurally of such character that it is not an attractive place for visitors, it could be made so at an expense not at all out of proportion to the advantages to be gained. The public is prone to judge its municipal water works by that which can be readily seen. The large investment in wells and distribution pipes is out of sight, and popular impressions as to the excellence of the water supply are usually based upon those things visible at the station.

It is perfectly practicable to make the municipal water works as attractive as any other park structure. The smoke can be reduced to a negligible quantity, - it is a detail of design,- and the coal can be handled in such a manner that there is no evidence of dust or dirt about the premises. It is practicable to construct the reservoir so that it will add to the attractiveness of the park, or, if desired, the reservoir can be entirely covered over and nothing visible but a mound or terrace, which, by the assistance of the landscape gardener,can be made as attractive as any other part of the park.

There is adjacent to the existing water works, a menagerie, housed in a number of small, poorly-maintained buildings. This class of structure, close to the water works, is extremely undesirable from a fire protection standpoint; and they should be moved to some other location in the park more remote from the water works, not only from the standpoint of safety from fire, but also for sanitary reasons. The existing buildings are of little value, and better structures should be provided, to be in keeping with the public park in South Bend.

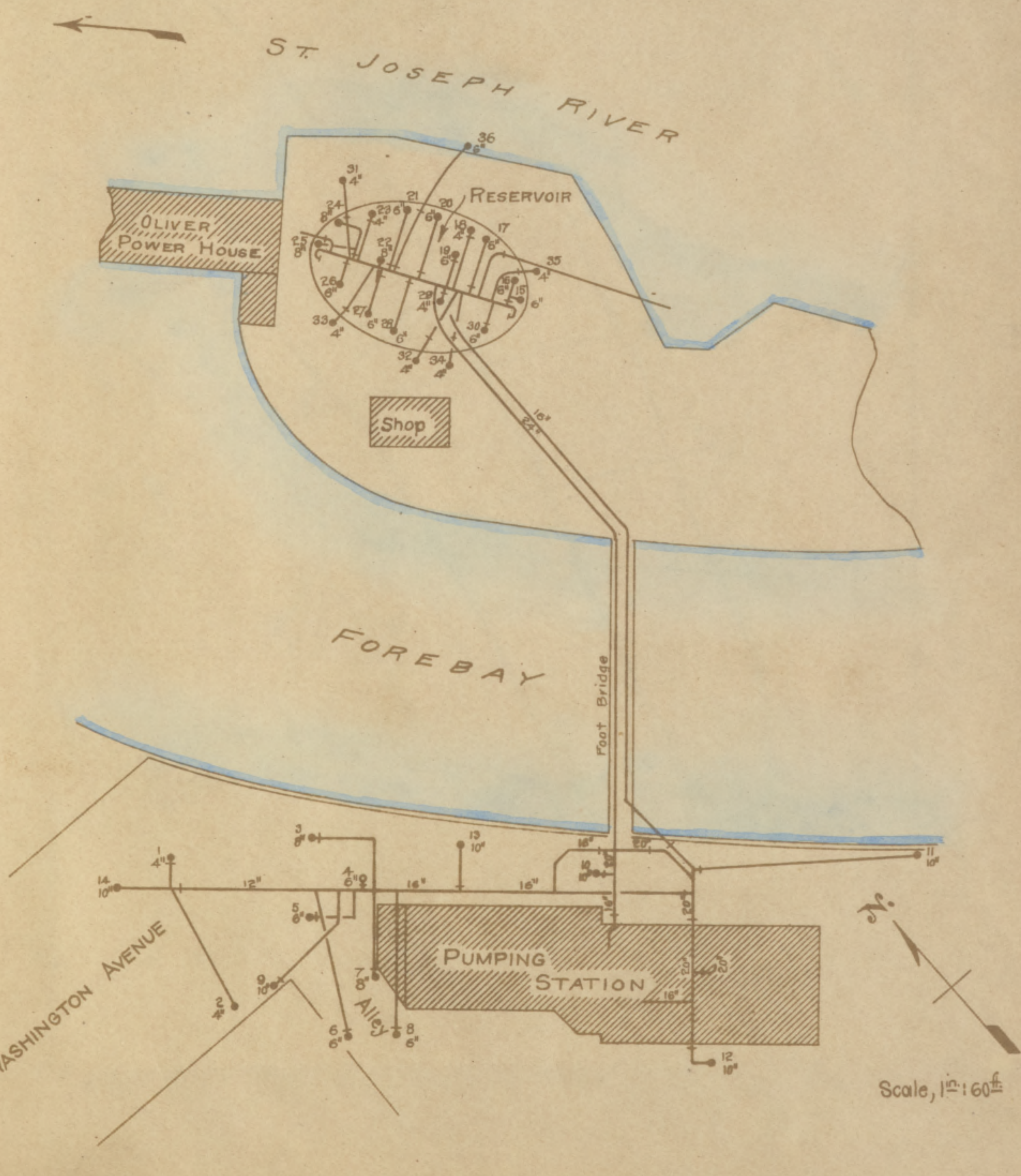
The City of South Bend is blessed with the possibility of securing a pure supply of ground water in the very heart of the distribution system, and such an important natural advantage should be used to its fullest extent.

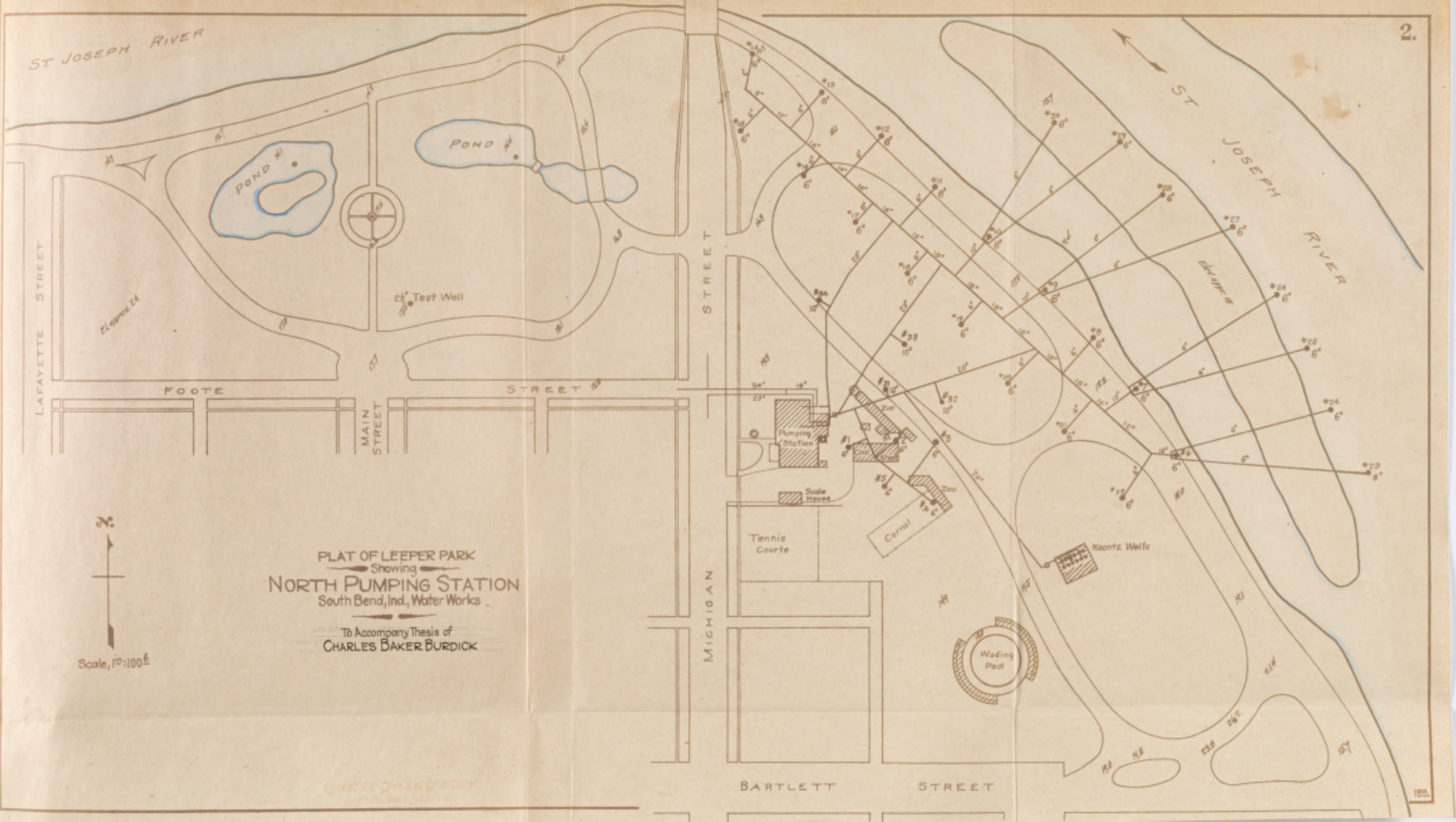
In the preparation of this report, acknowledgement is made of indebtedness for valuable information furnished by the City Engineer, Mr. William S. Moore, Mr. Thomas Ayres, Superintendent of the Water Works (whose long association with the plant and whose intimate knowledge thereof has been valuable); helpful assistance has also been found in the studies that have been made by Messrs. Burns & McDonnell, and in the reports made by Mr. Brownell, Professor R. L. Sackett, Chamberlain and Howell, and particularly in the report of Mr. A. J. Hammond, former City Engineer, which gives much valuable data in reference to the history of the plant and tests upon the old wells and pumping apparatus.

E X H I B I T S.

Plat Showing
LOCATION OF WELLS
at
CENTRAL PUMPING STATION
South Bend, Ind.

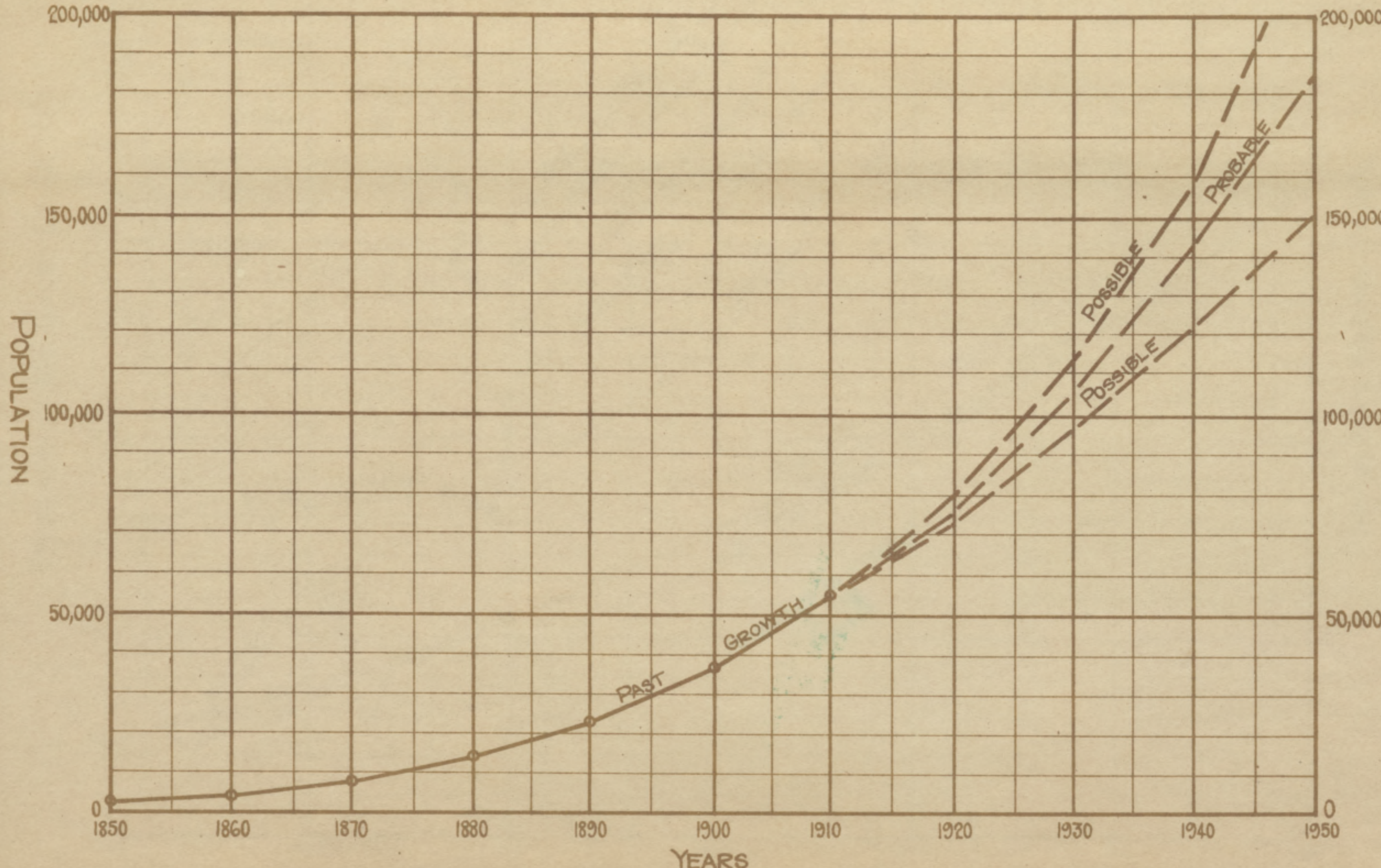
To Accompany Thesis of
CHARLES BAKER BURDICK




ST. JOSEPH RIVER
POND
POND
Test Well
LAFAYETTE STREET
FOOTE STREET
MAIN STREET
MICHIGAN STREET
Pumping Station
Coal Shed
Scale House
Tennis Courts
Corral
Zoo
Koontz Wells
Wading Pool
BARTLETT STREET
ST. JOSEPH RIVER
N.
Scale, 1 in = 100 ft.
PLAT OF LEEPER PARK
Showing
NORTH PUMPING STATION
South Bend, Ind., Water Works
To Accompany Thesis of
CHARLES BAKER BURDICK

Population Diagram
Showing
FUTURE ESTIMATED FROM PAST GROWTH
South Bend, Ind.

To Accompany Thesis of
CHARLES BAKER BURDICK



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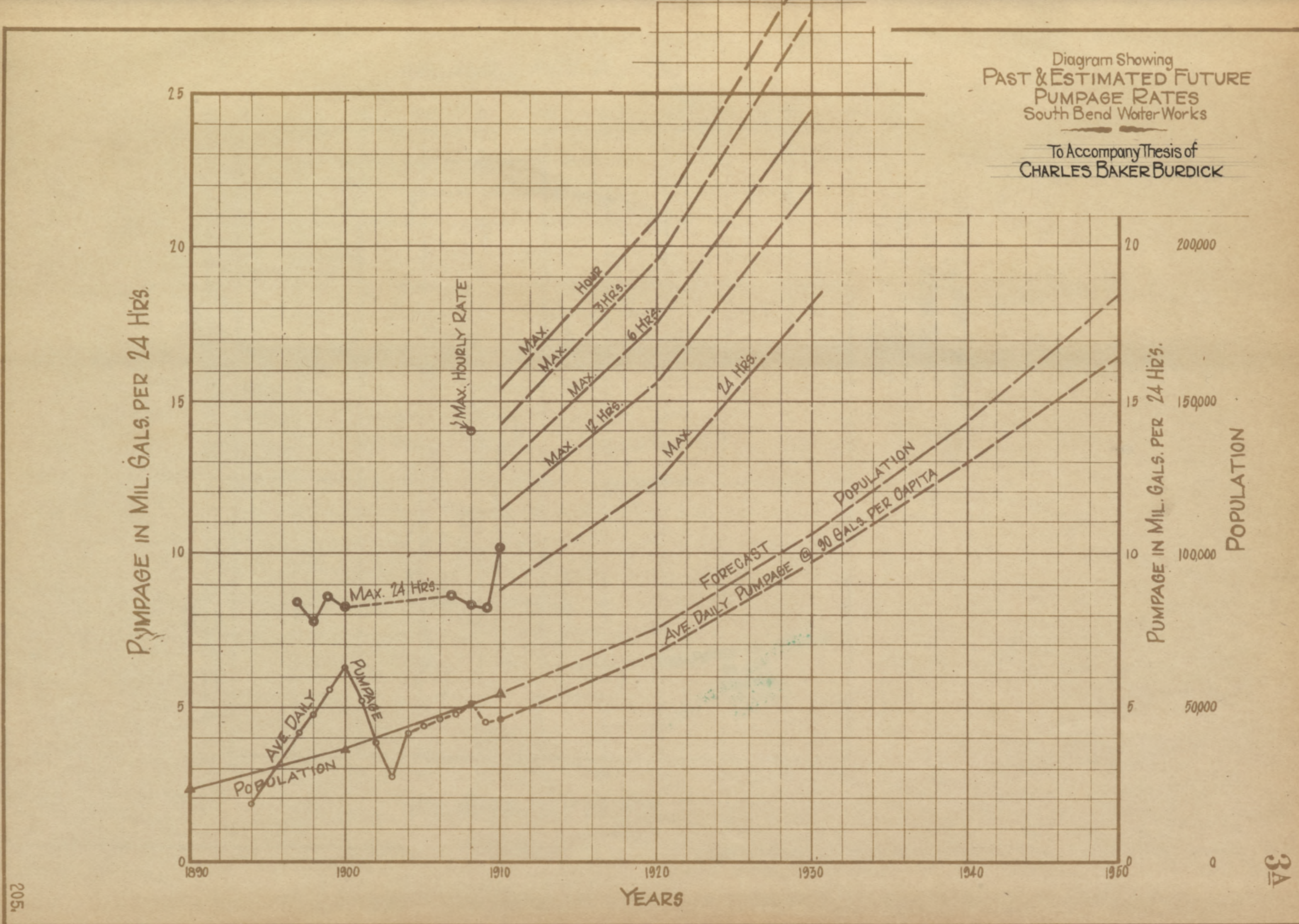


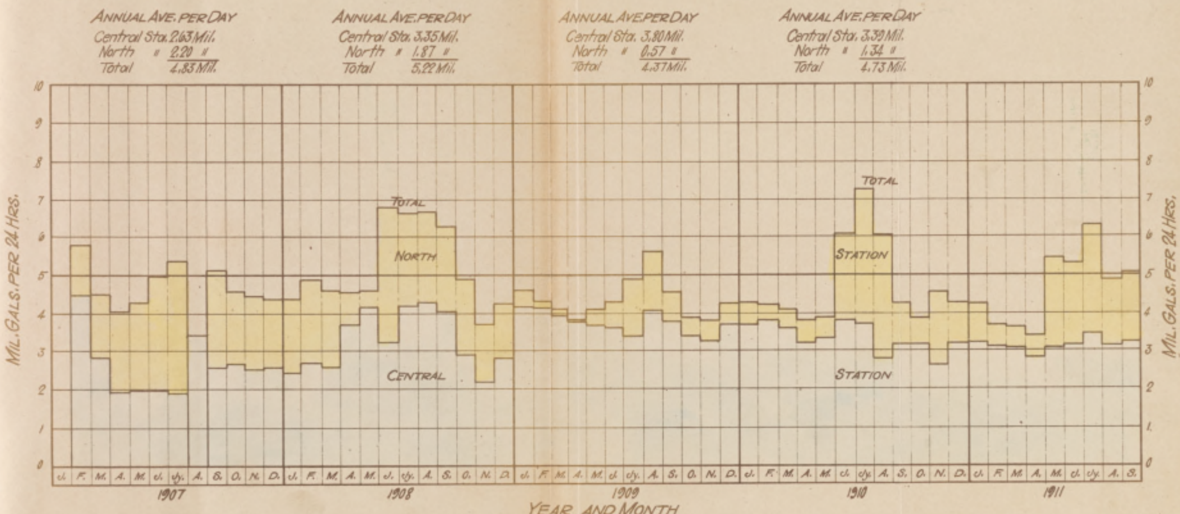
Diagram Showing
PAST & ESTIMATED FUTURE
PUMPAGE RATES
South Bend Water Works
To Accompany Thesis of
CHARLES BAKER BURDICK
PUMPAGE IN MIL. GALS. PER 24 HR'S.
PUMPAGE IN MIL. GALS. PER 24 HR'S.
POPULATION
YEARS
MAX. HOUR
MAX. 3 HR'S.
MAX. 6 HR'S.
MAX. 12 HR'S.
MAX. 24 HR'S.
MAX. HOURLY RATE
MAX. 24 HR'S.
FORECAST POPULATION
AVE. DAILY PUMPAGE @ 90 GALS PER CAPITA
AVE. DAILY PUMPAGE
POPULATION
0
5
10
15
20
25
1890
1900
1910
1920
1930
1940
1950
50,000
100,000
150,000
200,000

3A

205.

Diagram Showing
AVERAGE DAILY PUMPAGE IN EACH MONTH
South Bend Water Works
SOUTH BEND, IND.

To Accompany Thesis of
CHARLES BAKER BURDICK



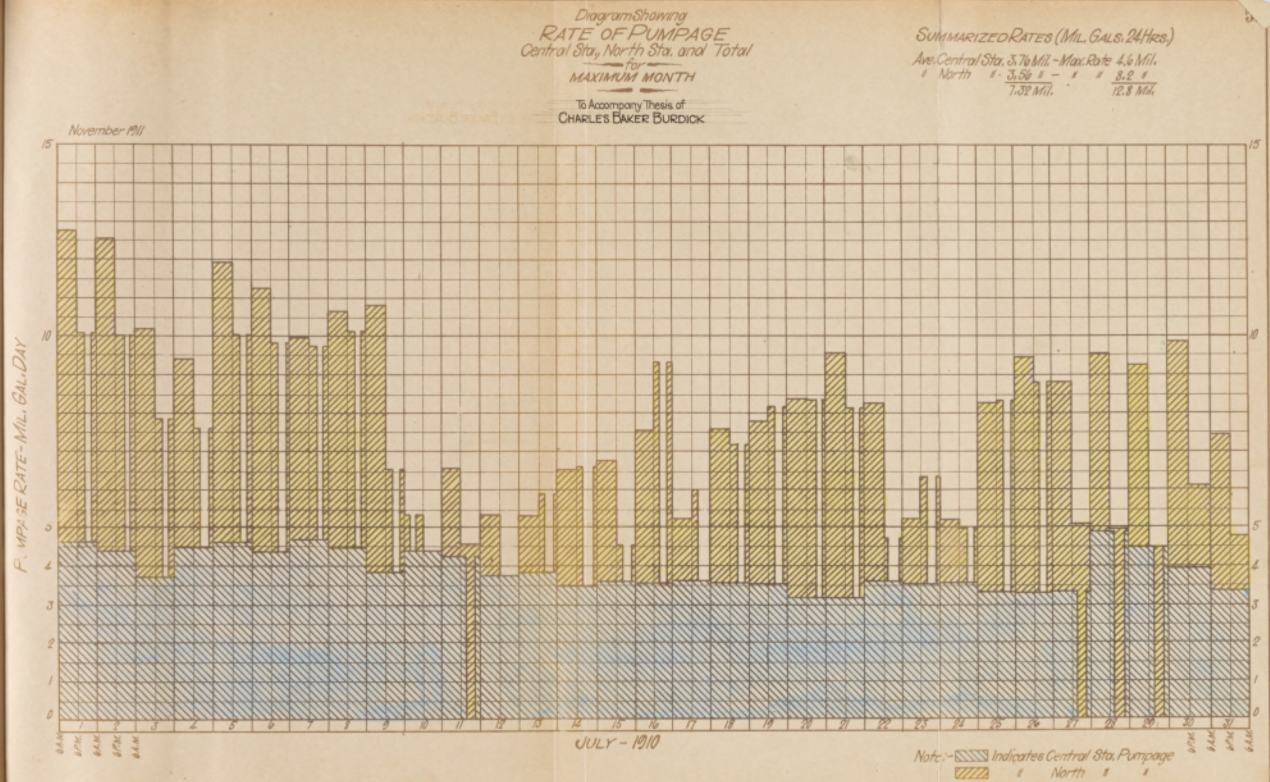


Diagram Showing
RATE OF PUMPAGE
Central Sta., North Sta. and Total
for
MAXIMUM MONTH
To Accompany Thesis of
CHARLES BAKER BURDICK
SUMMARIZED RATES (MIL. GALS. 24 HRS.)
Ave. Central Sta. 3.76 Mil. - Max. Rate 4.6 Mil.
" North " 3.56 " - " " 8.2 "
7.32 Mil.
12.8 Mil.
November 1911
PUMPAGE RATE - MIL. GAL. DAY
JULY - 1910
Note:- Indicates Central Sta. Pumpage
" North " "

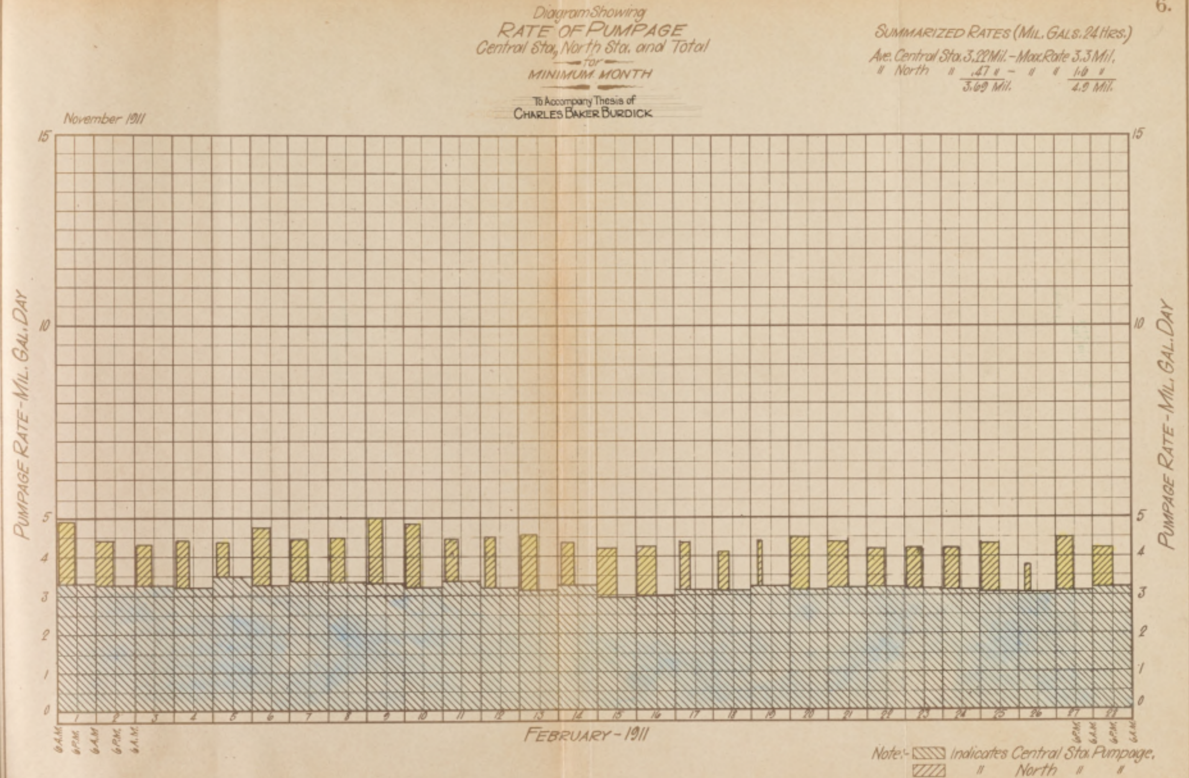


Diagram Showing
RATE OF PUMPAGE
Central Sta., North Sta. and Total
for
MINIMUM MONTH
To Accompany Thesis of
CHARLES BAKER BURDICK
SUMMARIZED RATES (MIL. GALS. 24 HRS.)
Ave. Central Sta. 3.22 Mil. - Max. Rate 3.3 Mil.
" North " .47 " - " " 1.6 "
3.69 Mil.
4.9 Mil.
November 1911
PUMPAGE RATE - MIL. GAL. DAY
15
10
5
4
3
2
1
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28
6 A.M.
6 P.M.
FEBRUARY - 1911
Note:- Indicates Central Sta. Pumpage.
" North " "

Diagram Showing
HOURLY RATE OF PUMPAGE
in Day of Maximum Consumption
SOUTH BEND WATER WORKS
(from Report of A. J. Hammond)

To Accompany Thesis of
CHARLES BAKER BURDICK

ANALYSES OF SOUTH BEND WATER
South Bend, Ind.

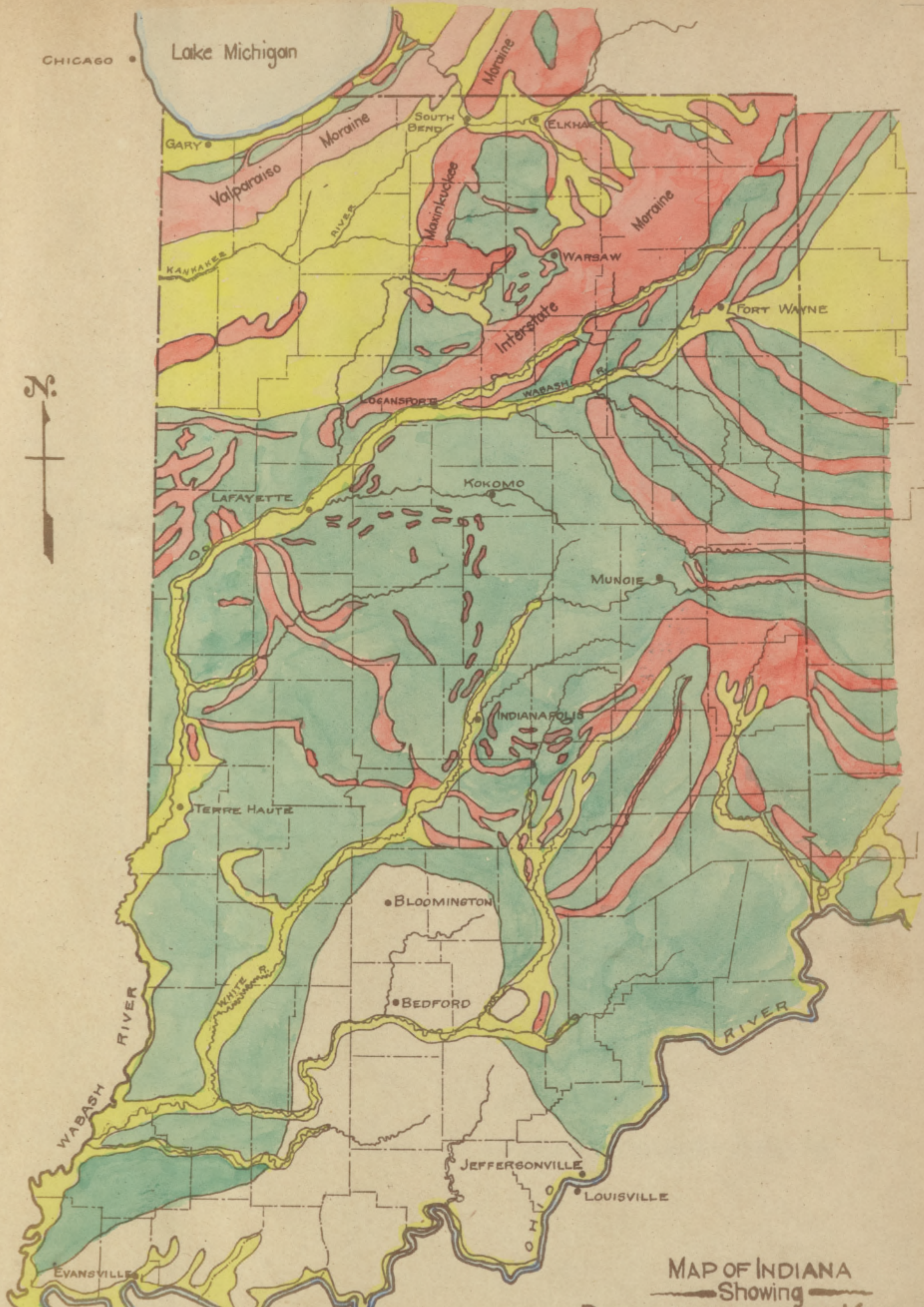
To Accompany Thesis of
CHARLES BAKER BURDICK

Note:- All results given in parts per 100,000

November 1911

ITEM	1 Tap Water	2 Tap Water	3 Portage Park	4 Echman St. Well.	5 N. Pump. Sta. Well 100' deep	6 Cen. Pump. Station	7 Portage Park Well. 100' deep	8 Well near Beck's Lake	9 St. Joe River at Benton Harbor
Date	1907	Fall 1909	Jan. 30. 1911	Oct. 3. 1910	Nov. 11. 1911	Nov. 11. 1911	Nov. 11. 1911	July 13. 1911	Dec. 23. 1909
Odor	.00	.00	.00	—	—	—	—	none	faint
Color	.00	.00	19.0	9.	7.0	7.0	7.0	9.	2.0
Turbidity	.00	.00	slight	slight	slight	slight	slight	very slight	Faint
Sediment	.00	.00	"	earthy	"	"	"	none	consid.
Free Ammonia	.0014	.0020	.0100	.014	.0000	.0000	.0080	.0160	.0030
Alb. "	.0054	.0035	.0004	.016	.0000	.0000	.0020	.0020	.0220
Nitrates	.00	.0800	.00	.00	.0000	.0300	.0000	.0000	.050
Nitrites	.0002	.00	.00	.00	.0001	.0002	.0000	.0000	.0001
Chlorine	1.4	1.2	.40	4.8	.60	2.80	.6	1.4	.4
Total Solids	36.6	37.6	51.6	46.4	29.0	52.2	28.2	28.0	
Fixed "	29.8	27.8	37.0	40.2	26.6	39.2	24.2	24.8	16.00
Hardness	24.6	23.0	21.0	25.8	20.8	24.2	20.8	21.2	20.00
Iron	.001	.08	..08	.20	.00	.00	.04	.08	.09
Lead	.00	.00	.00	.00	—	—	—	—	—
Colon Bacilli	.00	.00	.00	x yes	Gas Formers	Absent	Absent	Absent	yes

Tests #1-2-3-4 From Annual Reports South Bend.
Tests #5-6-7 by Jay Craven, Chemist, Indiana State Board of Health.
Test #8 by Barnard, Chemist, Indiana State Board of Health.
Test #9 by Michigan State Board of Health.
x Sample spoiled.

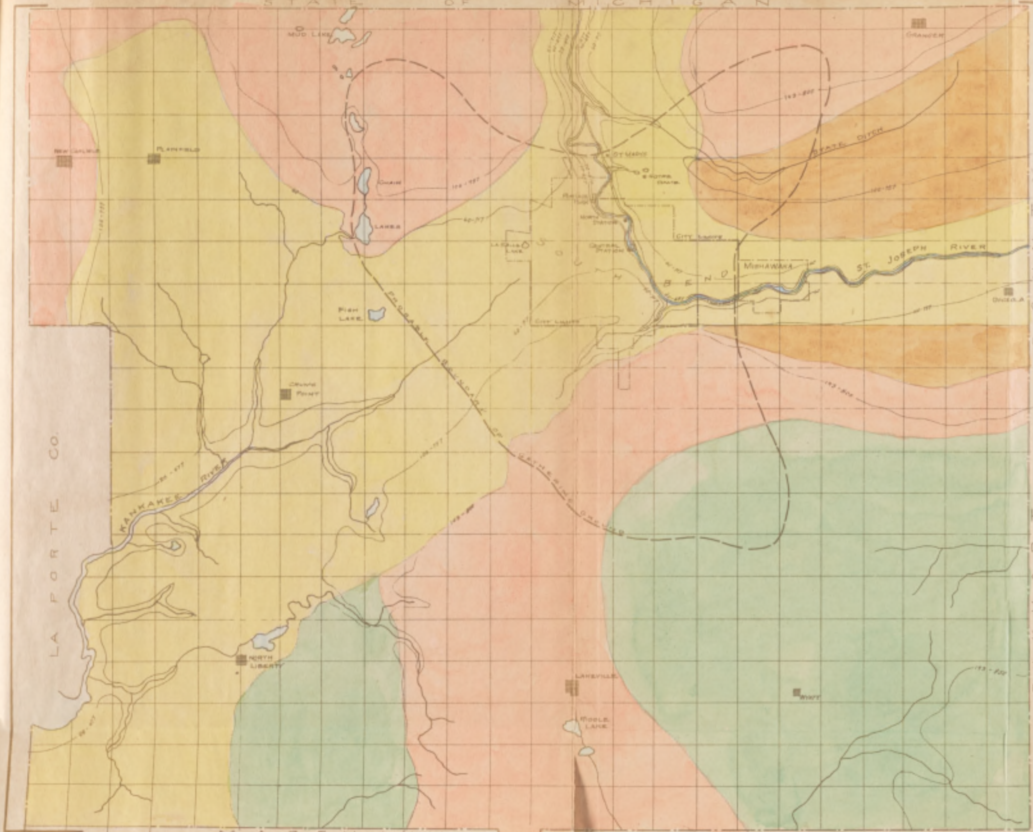


MAP OF INDIANA
Showing
DISTRIBUTION AND KIND OF GLACIAL DEPOSITS
(from Eighteenth Annual Report - U.S. Geol. Survey)

To Accompany Thesis of
CHARLES BAKER BURDICK

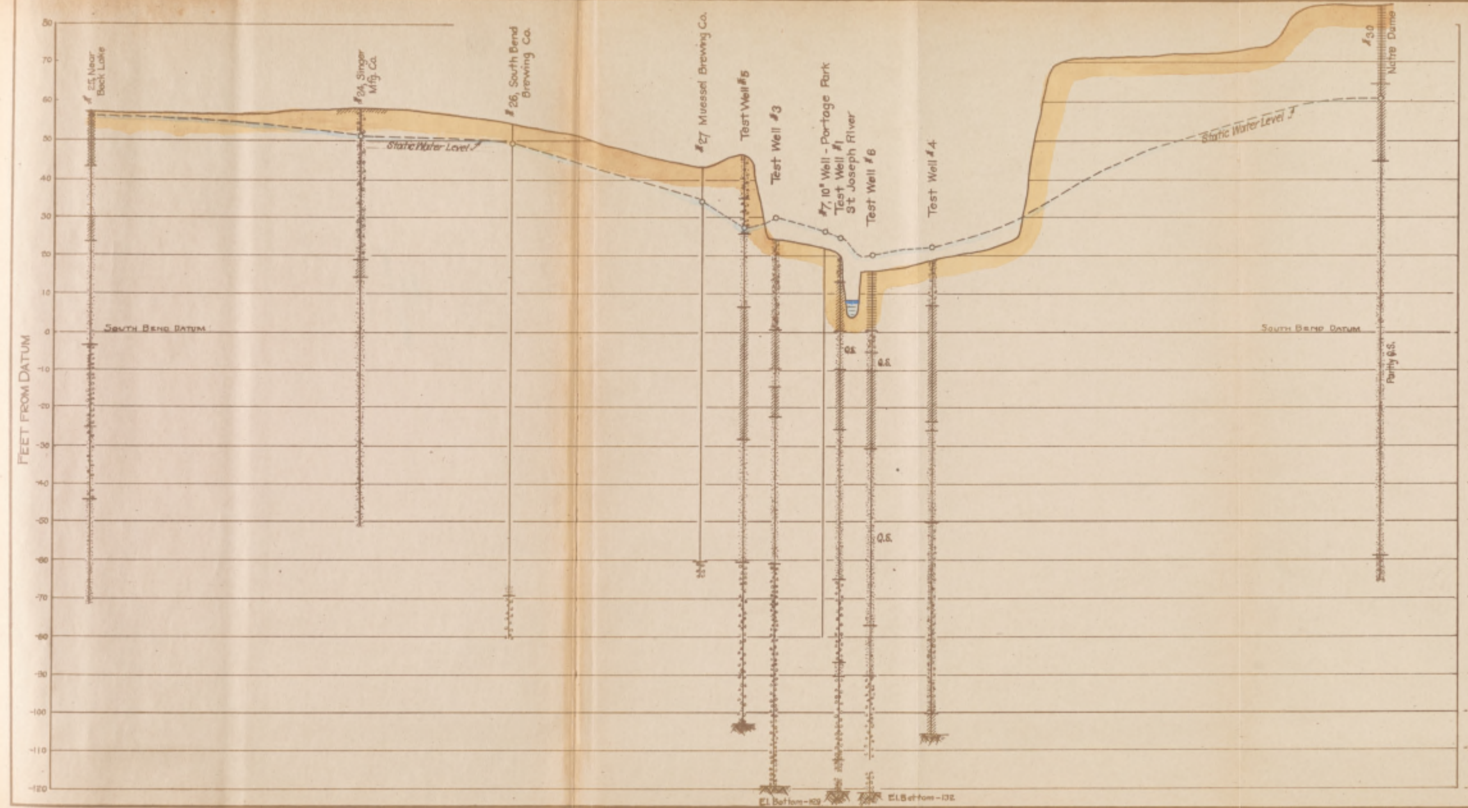
LEGEND

- Glacial Ridges
- Till Plains
- Loess covered till
- Valley Drift & Alluvium
- Extinct Lakes
- Unglaciated



MAP OF ST. JOSEPH COUNTY
Showing
CHARACTER & EXTENT OF GATHERING GROUND
South Bend Water Works
(Geological Data - U.S. Water Supply Paper #254)
Scale, 1 in. : 2 mi.

To Accompany Thesis of
CHARLES BAKER BURDICK



GEOLOGICAL SECTION
North East & South West from Portage Pk.
Showing
SUBSTRATA & STATIC WATER LEVELS

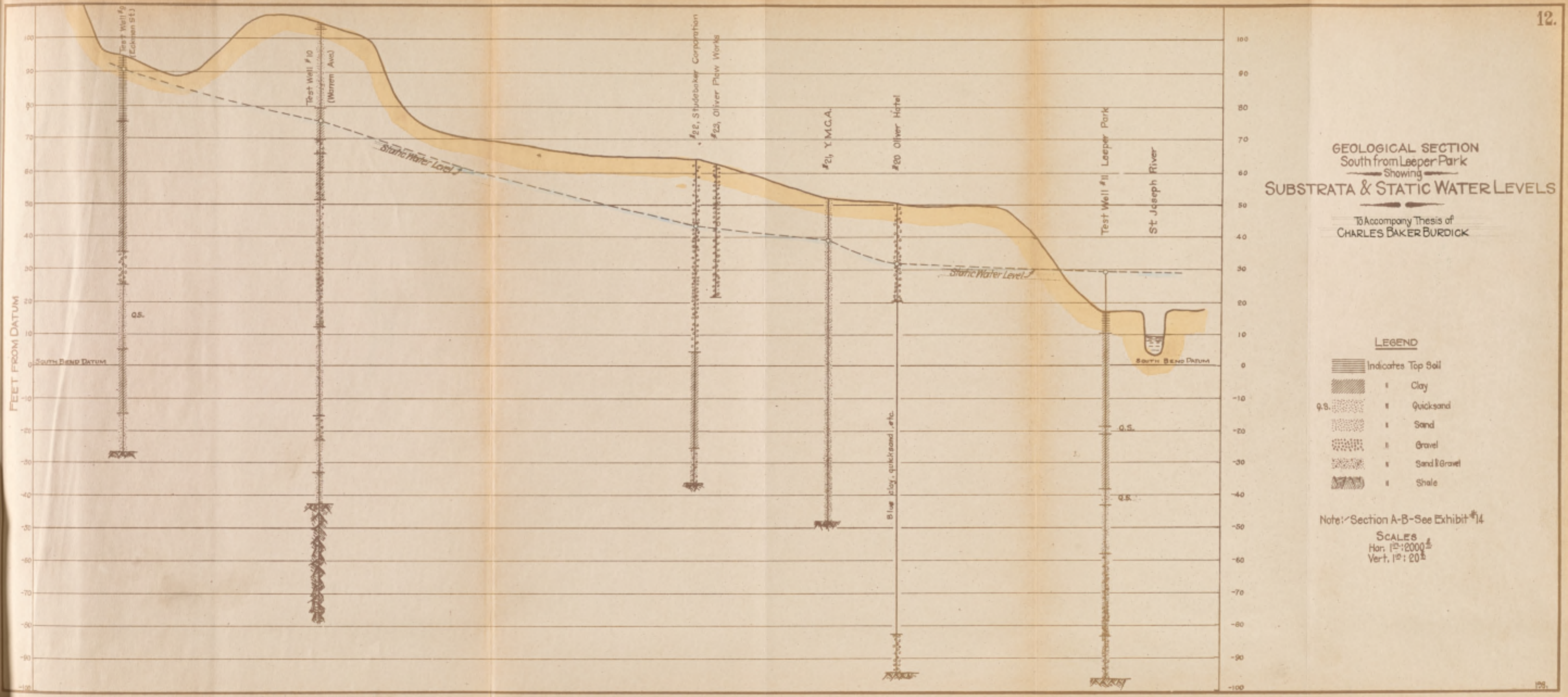
To Accompany Thesis of
CHARLES BAKER BURDICK

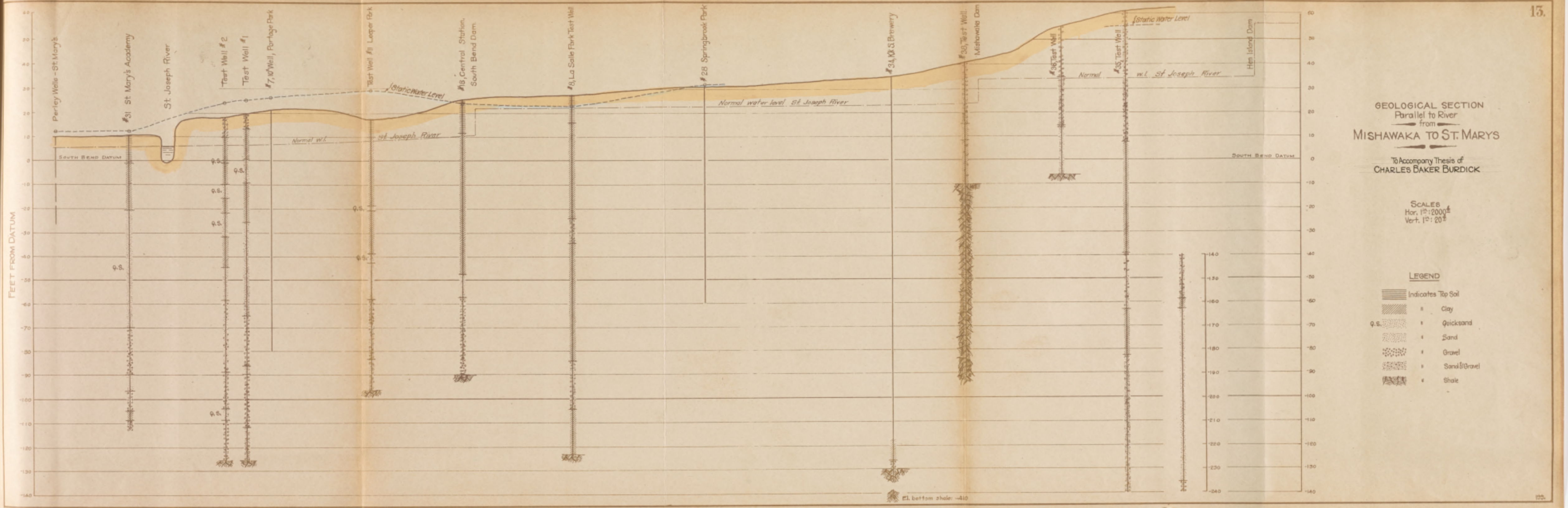
LEGEND

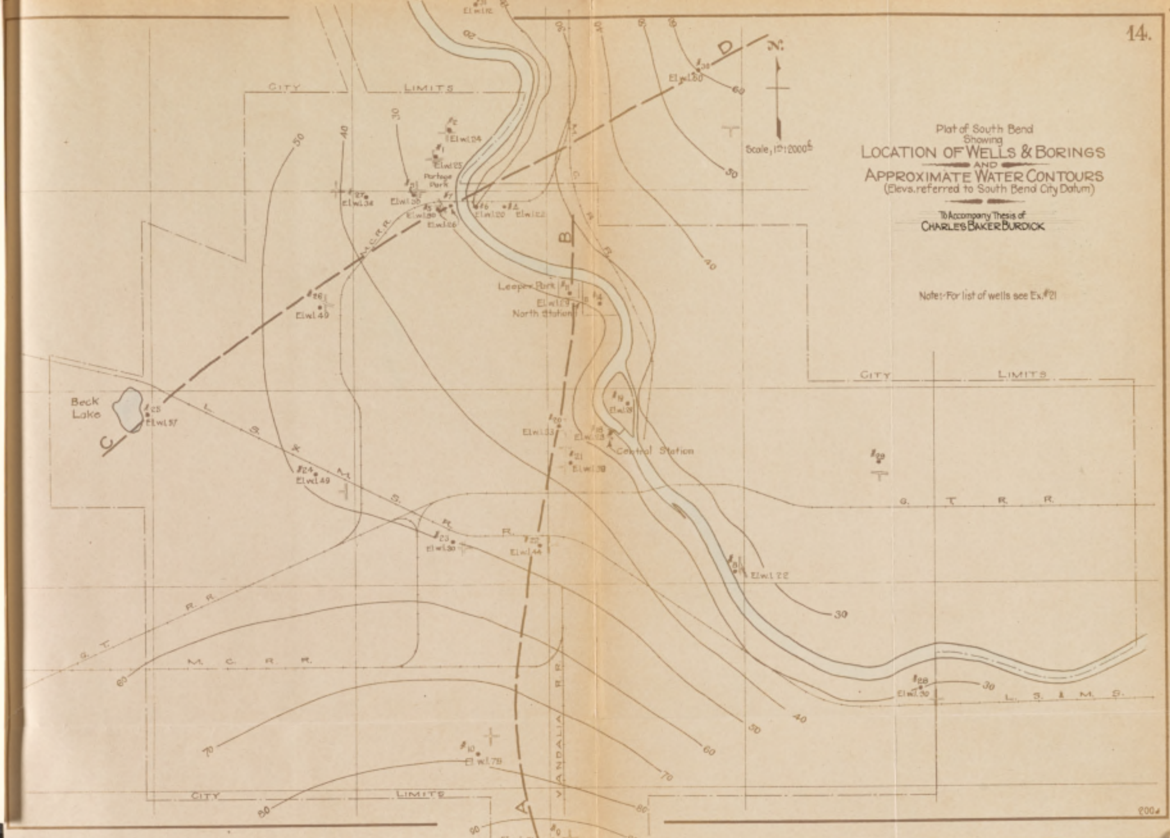
Indicates Black Dirt
" Top Soil
" Clay
Q.S. " Quicksand
" Sand
" Gravel
" Sand & Gravel
" Shale

Note:- Section C-D- See Exhibit #14

SCALES
Hor. 1 in : 2000 ft
Vert. 1 in : 20 ft


GEOLOGICAL SECTION
South from Leeper Park
Showing
SUBSTRATA & STATIC WATER LEVELS
To Accompany Thesis of
CHARLES BAKER BURDICK
Test Well #9 (Eckman St.)
Test Well #10 (Warren Ave.)
#22, Studebaker Corporation
#23, Oliver Plow Works
#21, Y.M.C.A.
#20 Oliver Hotel
Test Well #11 Leeper Park
St Joseph River
Static Water Level
Static Water Level
South Bend Datum
Feet From Datum
Q.S.
Blue clay, quicksand, etc.
LEGEND
Indicates Top Soil
" Clay
Q.S. " Quicksand
" Sand
" Gravel
" Sand & Gravel
" Shale
Note:- Section A-B-See Exhibit #14
SCALES
Hor. 1in : 2000ft
Vert. 1in : 20ft


Perley Wells - St. Mary's
#31 St. Mary's Academy
St. Joseph River
Test Well #2
Test Well #1
#7, 10" Well, Portage Park
Test Well #11 Leeper Park
Static Water Level
#18, Central Station, South Bend Dam.
#13, La Salle Park Test Well
#28 Springbrook Park
#34, K. & S. Brewery
#30, Test Well. Mishawaka Dam
#36 Test Well
#35 Test Well
Hen Island Dam
Normal water level St. Joseph River
Normal W.L. St. Joseph River
South Bend Datum
Q.S.
Feet from Datum
El. bottom shale: -410
GEOLOGICAL SECTION
Parallel to River
from
MISHAWAKA TO ST. MARYS
To Accompany Thesis of
CHARLES BAKER BURDICK
SCALES
Hor. 1 in : 2000 ft
Vert. 1 in : 20 ft
LEGEND
Indicates Top Soil
" Clay
Q.S. " Quicksand
" Sand
" Gravel
" Sand & Gravel
" Shale



14.
Plat of South Bend
Showing
LOCATION OF WELLS & BORINGS
AND
APPROXIMATE WATER CONTOURS
(Elevs. referred to South Bend City Datum)
To Accompany Thesis of
CHARLES BAKER BURDICK
Scale, 1 in = 2000 ft
N.
Note:- For list of wells see Ex. #21
CITY LIMITS
CITY LIMITS
CITY LIMITS
Portage Park
Leeper Park
North Station
Central Station
Beck Lake
L. S. & M. S. R. R.
G. T. R. R.
M. C. R. R.
VANDALIA R. R.

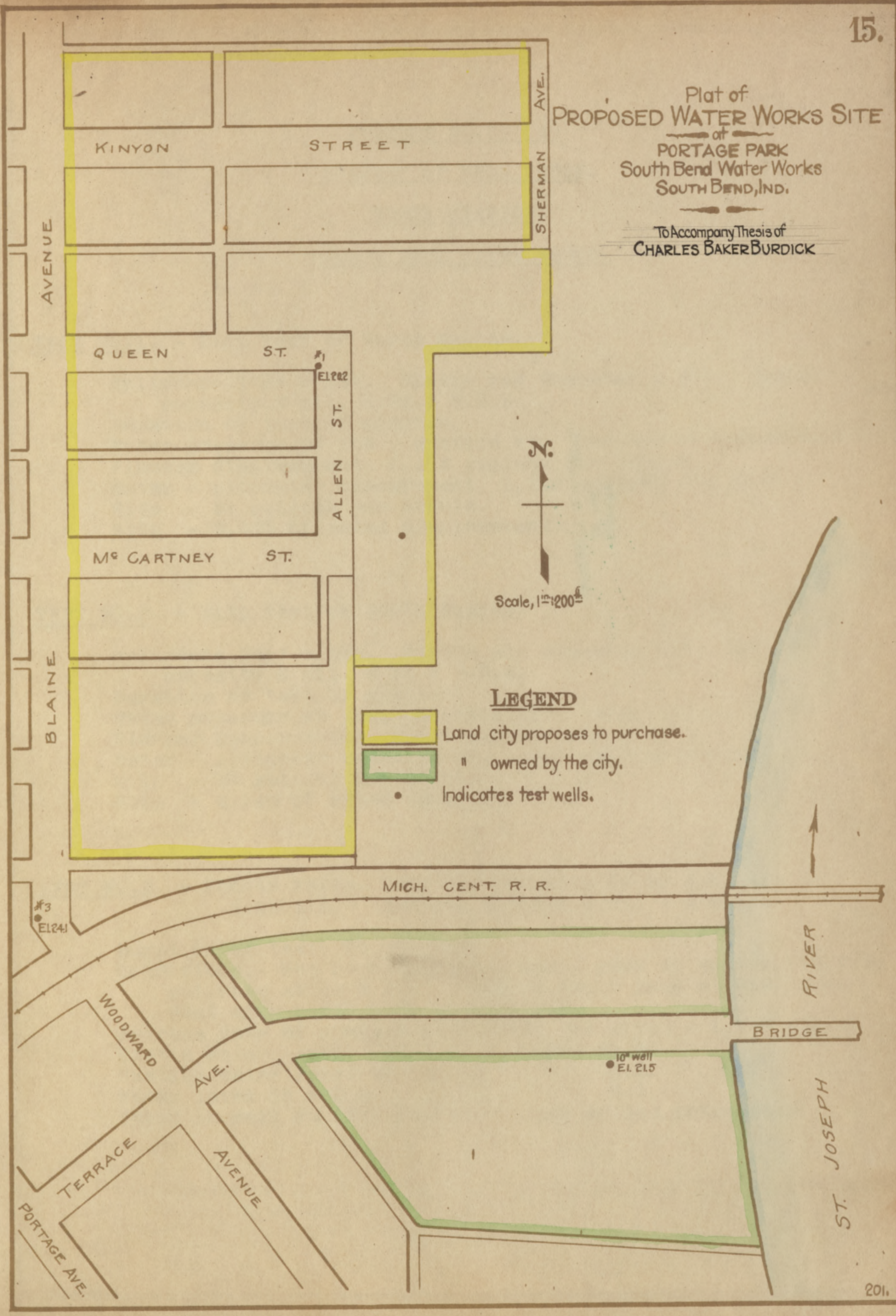

Plat of
PROPOSED WATER WORKS SITE
at
PORTAGE PARK
South Bend Water Works
South Bend, Ind.
To Accompany Thesis of
CHARLES BAKER BURDICK
KINYON STREET
SHERMAN AVE.
AVENUE
BLAINE
QUEEN ST.
#1
El. 28.2
ALLEN ST.
McCARTNEY ST.
N.
Scale, 1 in. : 200 ft.
LEGEND
Land city proposes to purchase.
" owned by the city.
Indicates test wells.
MICH. CENT. R. R.
#3
El. 24.1
WOODWARD
AVE.
TERRACE
AVENUE
PORTAGE AVE.
BRIDGE
10" well
El. 21.5
RIVER
ST. JOSEPH

EXHIBIT NO.16 (a)

SUMMARY OF WELL TESTS.

NORTH STATION.

SOUTH BEND WATER WORKS.

TEST NO.1. - Slip Test of North Engine.

Cylinders.17½" x 24". Piston rod diameter = 3¾". Rated capacity.3 mil. @ 21.3 R.P.M.
Duration of test.10 minutes.
Water pressure.85 lbs., suction.8". Average stroke.21.8".
Plunger displacement, 1,175 gallons per minute.
Water - pitometer measurement, 1,149 gallons per minute.
Slip - 26 gallons per minute.
Slip - 2.02% of rated displacement.

TEST NO.2. - Slip Test of South Engine.

Cylinders.24½" x 36". Piston rod diameter, 4½". Rated capacity.6 mil. @ 14.4 R.P.M.
Duration of test.14 minutes.
Water pressure.85 lbs. Suction,11". Aver.stroke.31.7".
Plunger displacement, 2,085 gallons per minute.
Water - pitometer measurement, 1,987 gallons per minute.
Slip - 98 gallons per minute.
Slip - 4.14% of rated capacity.

TEST NO.3. - Koontz Wells, Pair #1, Oct.20th (9:20 A.M. to 9:45 A.M.) Average spacing, 4 ft. - 2 wells.

Duration of test, 25 minutes.
Conditions,- Had been operating small pump at approx.1.5 mil. gal.rate since 6 A.M. Started south pump at 9:20 A.M. Shut down north pump at 9:22 A.M.
Average rate of pumpage (corrected for slip) - 1,830 g.p.m.

Static water level,	Datum	29.5.
Suction water level at engine,	"	5.1.
Water level in wells,	"	5.1.

Water in well #2 (250 ft.from Koontz wells), Datum 23.9.

EXHIBIT NO.16 (a)-(Cont'd).

TEST NO.4. - Koontz Wells, - Pairs #1 and 9. Oct.20th.
(9:45 A.M. to 10:00 A.M.) Average spacing, 6-2/3'.

Duration of test, 15 minutes.
Conditions - followed #3 test.

Average rate of pumpage (corrected)	2,320	g.p.m.
Static water level,	Datum	29.5.
Suction water level at engine.	"	8.0.
Water level in wells,	"	6.2.
Water in well No.2 (250' distant),	"	23.6.

TEST NO.5. - Koontz Wells, - Pairs #1, 5 and 9. Oct.20th.
(10:00 A.M. to 10:20 A.M.) Average spacing, 4' - 6 wells.

Duration of test, 20 minutes.
Conditions - followed #4 test.

Average rate of pumpage (corrected)	2,900	g.p.m.
Static water level,	Datum	29.5.
Suction water level at engine,	"	4.6.
Water level in wells,	"	7.3.
Water in well No.2 (250' distant),	"	20.9.

TEST NO.6. - Koontz Wells, - Pairs #1, 5, 9 and 7, Oct.20th.
(10:20 A.M. to 10:45 A.M.)

Duration of test, 25 minutes.
Conditions - followed test #5.

Average rate of pumpage (corrected)	3,070	g.p.m.
Static water level,	Datum	29.5.
Suction water level at engine,	"	4.4.
Water level in wells,	"	7.3.
Water level in well No.2 (250' distant)	"	20.4.

TEST NO.7. - Koontz Wells, - Pairs #1, 5, 9, 7 and 3, Oct.20th.
(10:45 A.M. to 11:05 A.M.)

Duration of test, 20 minutes.
Conditions - followed test #6.

Average rate of pumpage (corrected)	3,220	g.p.m.
Static water level,	Datum	29.5.
Suction water level at engine,	"	3.5.
Water level in wells,	"	8.2.
Water level in well #2 (250' distant)	"	20.9.

EXHIBIT NO.16 (a)-(CONT'D).

TEST NO.8. - Koontz Wells, - Pairs #1, 5, 9, 7, 3 and 11.
Oct.20th. (11:05 A.M. to 11:20 A.M.) Average spacing, 5' - 12 wells.

Duration of test, 15 minutes.	
Conditions - followed test #7.	
Average rate of pumpage (corrected),	3,310 g.p.m.
Static water level,	Datum 29.5.
Suction water level at engine,	" 4.3.
Water level in wells,	" 8.0.
Water level in well #2 (250' distant),	" 19.9.

TEST NO.9. - Koontz Wells,- All, (same as in test #8), Oct.20th, (11:20 A.M. to 12:00 M.).

Duration of test, 40 minutes.	
Conditions - same as in #8, except air pump now running.	
Average rate of pumpage (corrected)	3,400 g.p.m.
Static water level,	Datum 29.5.
Suction water level at engine,	" 3.5.
Water level in wells,	" 8.2.
Water level in well #2 (250' distant),	" 19.4.

TEST NO.10. - All Wells. Oct.27th (8:00 A.M. to 11:10 A.M.)

Duration of test, 3 hours, 10 minutes. (Readings during last 1 hr. 50 min. only used here from 9:20 to 11:10 A.M.)

Conditions - From 6:00 A.M. to 8:00 A.M. pumped at approx. 1.5 mil. rate with north pump.

Air pump in operation,- South pump drawing on wells #1 - 5 and Koontz.

North Pump - Av. rate of pumpage (corrected)	2,440 g.p.m.
Static water level,	Datum 29.5.
Suction water level at engine,	" -1.5.
Water level in well #14,	" 0.9.
Water level in " #18,	" 1.5.
Water level in " #34,	" 0.3.
Water level in test well (600' distant)	" 18.2.
" " " well #7,	" 0.9
South Pump - Av.rate of pumpage (corrected)	4,160 g.p.m.
Suction water level at engine,	Datum -2.9.
Water level in Koontz wells,	" 0.9.
Water level in well #7 (200' distant),	" 0.9 (Connected to other pump).

EXHIBIT NO.16 (a)-(CONT'D).

TEST NO.11. - Wells #1 to 5, 7, 8, 10, 12, 14, 16, 18, 19, 22, 24, 26, 28, 30, 32 to 34 and 4 Koontz wells, Oct.27th. (1:30 P.M. to 2:10 P.M.), 22 wells out of service, 24 wells in service.

Duration of test, 40 minutes.
Conditions - Pumping approx. 5,000 g.p.m.since 11:10 A.M.; from 11:10 A.M. to 12 M. cut out 6" wells as above indicated and one 10" well. At 1:10 opened valves connecting suction lines; 1:15 P.M. to 1:30 P.M. cut out 8 Koontz wells. Spacing of wells approx. 150'.
Average rate of pumpage (corrected) North Pump 1,510.
South " 3,990.
5,500 g.p.m.

Static water level,	Datum	29.5.
Suction water level N.engine,	"	-3.2.
" " " S. "	"	-3.3.
Water level in Koontz well,	"	2.0.
" " " Well #2,	"	2.3.
" " " " #7,	"	-3.4.
" " " " #14,	"	-4.3)
" " " " #18,	"	-3.8)not simultaneous.
" " " " #34,	"	-5.2)
" " " test well (600' distant)	datum	18.8.

TEST NO.12. - Wells as in test #11, Oct.27th. (2:10 P.M. to 2:40 P.M.)

Conditions same as in previous test except pumping only with south pump.

Duration of test, 30 minutes.
Average rate of pumpage, 4,970 g.p.m.

Static water level,	Datum	29.5.
Suction water level at engine,	"	-2.5
Water level in Koontz wells,	"	2.8.
" " " well #2,	"	4.8.
" " " " #7,	"	-2.1.
" " " " #14,	"	-1.3)
" " " " #18,	"	-1.9)not simultaneous.
" " " " #34, (Aver.)	"	-1.9.
" " test wells,	not measured.	

EXHIBIT NO.16 (a)-(CONT'D).

TEST NO.13. Wells as in Test #11, except all Koontz wells off.- Oct.27th, (2:40 P.M. - 3:05 P.M.)

Duration of test, 25 minutes. (Out of service, 30 wells; in service, 16 wells.)

Conditions same as in previous test except Koontz well now off.

Average rate of pumpage, 3,720 g.p.m. = 5.3 mil.		
Static water level,	Datum	29.5.
Suction water level at engine,	"	-4.2.
Water level at well #2,	"	1.5)
" " " " #7,	"	-4.6) not
" " " " #14,	"	-1.4)simultaneous.
" " " " #18,	"	-4.)

TEST NO.14. All wells except Koontz - Oct.27th. (3:40 P.M. to 4:30 P.M.)

Duration of test, 50 minutes.

Conditions - between 3:10 P.M. and 3:40 P.M. turned on wells #17-15-13-11-9-20-6-21-31-23-25-27 and 29.

Average rate of pumpage, 3,720 g.p.m. = 5.3 mil.		
Static water level,	Datum	29.5.
Suction water level at pump,	"	2.3.
Water level at well #2,	"	+8.3.
" " " " #7,	"	1.0.
" " " " #19,	"	3.1
" " " " #14,	"	2.7) not
" " " " #18,	"	2.0)simultaneous.
" " " " #34,	"	3.7)

EXHIBIT NO.16 (b).

SUMMARY OF WELL TESTS.

CENTRAL STATION.

SOUTH BEND WATER WORKS.

TEST NO.1. - Slip Test of North Engine,- Oct.16th,1911.
(9:39 P.M. to 9:49 P.M.)

Cylinders,16" x 18". Piston rod diameter,2-5/8". Rated capacity,$2\frac{1}{2}$ mil. @ 28 R.P.M.
Duration of test, 10 minutes.
Water pressure, 85#. Suction,11".
Plunger displacement, 11,180 gallons.
Water - pitometer measurement, 9,896.
Slip - 128.4 gallons per minute.
Slip - 11.5 per cent.of displacement.

TEST NO.2. - Slip Test of South Engine,- Oct.17th.

Cylinder,16" x 18". Piston rod diameter,2-5/8". Rated capacity,$2\frac{1}{2}$ mil. @ 28 R.P.M.
Duration of test, 10 minutes.
Water pressure,85#. Suction,11".
Plunger displacement, 10,000 gallons.
Water - pitometer measurement, 9,980 g.p.m.
Slip - 2 gallons per minute.
Slip - 0.2 per cent.of displacement.

TEST NO.3. - All wells except #17-23-29-34-35-5 and 30.
Oct.19th, (8:30 A.M. to 9:00 A.M.)

Duration of test, 30 minutes.
Conditions - both pumps running, also air pump; had been running continuously before test.
Average rate of pumpage (corrected for slip) 2,250 gals.per min.

Static water level,	Datum	24.16.
Suction water level at south engine,	"	9.9.
Water level at north engine,	"	8.2.
Water level suction line in reservoir,	"	8.6.
Water level well #5,	"	15.3.
Water level wells near #5,	"	9.3.

EXHIBIT NO.16 (b)-(CONT'D).

TEST NO.4. - All wells of south group except #5 and #10.
Oct.19th. (9:30 A.M. to 10:00 A.M.)

Duration of test, 30 minutes.
Conditions - Shut down during previous ½ hour. Pumping with south pump only.
Average rate of pumpage - 1,240 g.p.m. = 1.8 mil.

Static water level,	Datum	24.16.
Suction water level at south engine,	"	10.4
Water level well #5,	"	17.7.
Water level wells near #5 (approx.)	"	11.7.
Water level well #29,	"	19.2.

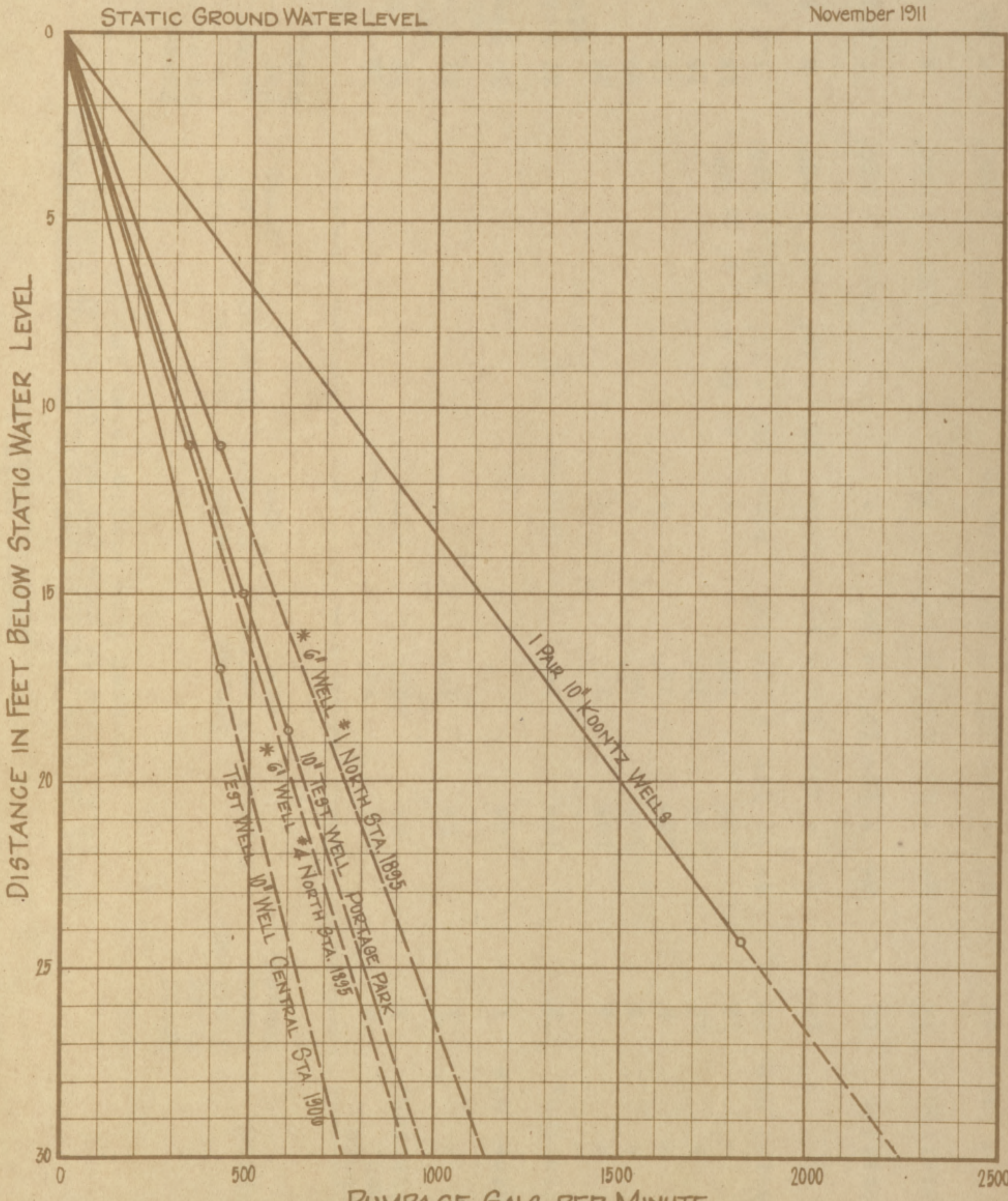
TEST NO.5. - Wells of north group except #23,17,30,34,35 and 29, and those of south group #10 being on,- Oct.19th. (10:40 A.M. to 11:10 A.M.)

Duration of test, 30 minutes.
Conditions - Shut down from 10:00 to 10:40 A.M. Operating only North pump during test.
Average rate of pumpage, 1,075 g.p.m. = 1.54.

Static water level,	Datum	24.16.
Suction water level at north engine,	"	12.1.
Water level well #5,	"	21.0.
Water level well #29,	"	17.1.
Water level well suction line,	"	11.9.

Diagram Showing
RELATIVE CAPACITIES OF VARIOUS WELLS
Tested alone without interference by other wells.
SOUTH BEND, IND.

To Accompany Thesis of
CHARLES BAKER BURDICK



* Note:- As reported by A.J. Hammond, three other wells lie between extremes shown.

EXHIBIT NO.17 A.

TABLE SHOWING SPECIFIC CAPACITY OF SOUTH BEND WELLS.
(i.e. Yield in gals.per min.per ft.of draft.
measured from static water level).

Place.	No.of Wells Simultaneously Pumped.	Size.	Length Strainers.	Mesh Strainers.	Approx. Spacing.	Area of Group.	Specific Capacity per Well.	Remarks.
Portage Park,	1	10"	16'	Coarse			32	Test new well in 1911.
N.Station,	1	6"	10'	Fine			38	Best of 5 wells, when new in 1895.
" "	1	6"	10'	"			31	Poorest of 5 wells when new in 1895.
Central Sta..	1	10"					30	Test in 1906, new well.
N.Station,	2	10"	16'	Coarse	4'		37	Koontz wells, 1 yr. old. Tested 1911.
" "	4	10"	16'	"			25	Ditto.
" "	6	10"	16'	"			22	Ditto.
" "	8	10"	16'	"			17	Ditto.
" "	10	10"	16'	"			15	Ditto.
" "	12	10"	16'	"	4' to 6'	6' x 20'	13	Ditto.
Central Sta.	12	4" to 10"	9' to 12'	Fine	50' " 70'	80' x 310'	7.5	South group, average, 16 yrs.
" "	19	4" " 10"	9' " 12'	"	10' " 15'	60' x 90'	5.	North group, average, 23 yrs.
N.Station	16	6" " 10"	10' " 16'	"		1000' x 550'	7.3	All old wells, average, 15 yrs.
N.Station,	34	6" " 10"	10' " 16'	"		1000' x 550'	4.0	All old wells, average, 15 yrs.
" " (all)	46	6" " 10"	10' " 16'	Fine to Coarse		1000' x 550'	5.05	Av.age, 11 yrs. (Incl. Koontz Wells
" " "	29	4" " 10"	9' " 12'	Fine		310' x 320'	5.3	Av.age, 20 yrs.

Diagram Showing

RESULT OF TEST ON KOONTZ WELLS

South Bend Water Works

To Accompany Thesis of
CHARLES BAKER BURDICK

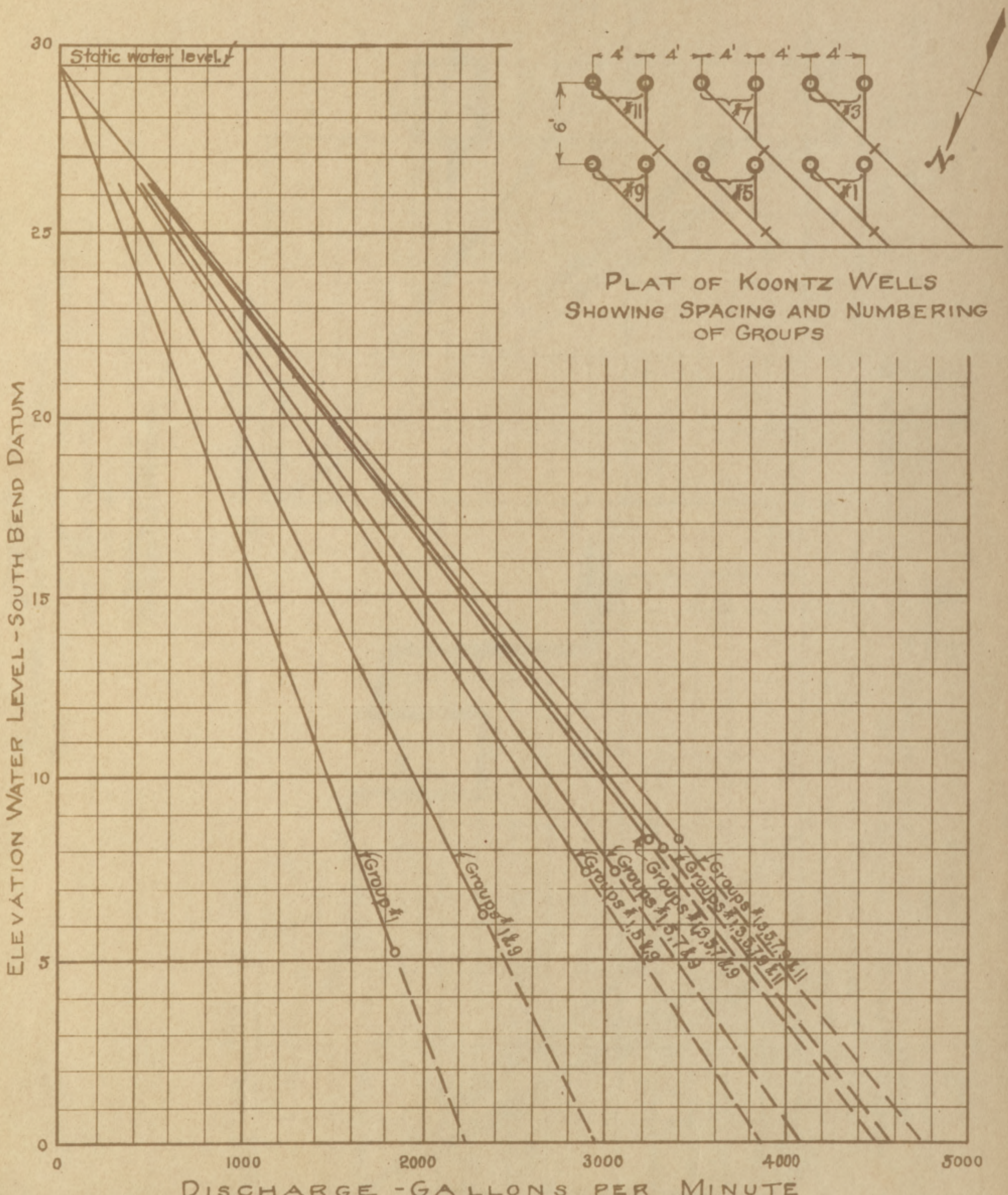
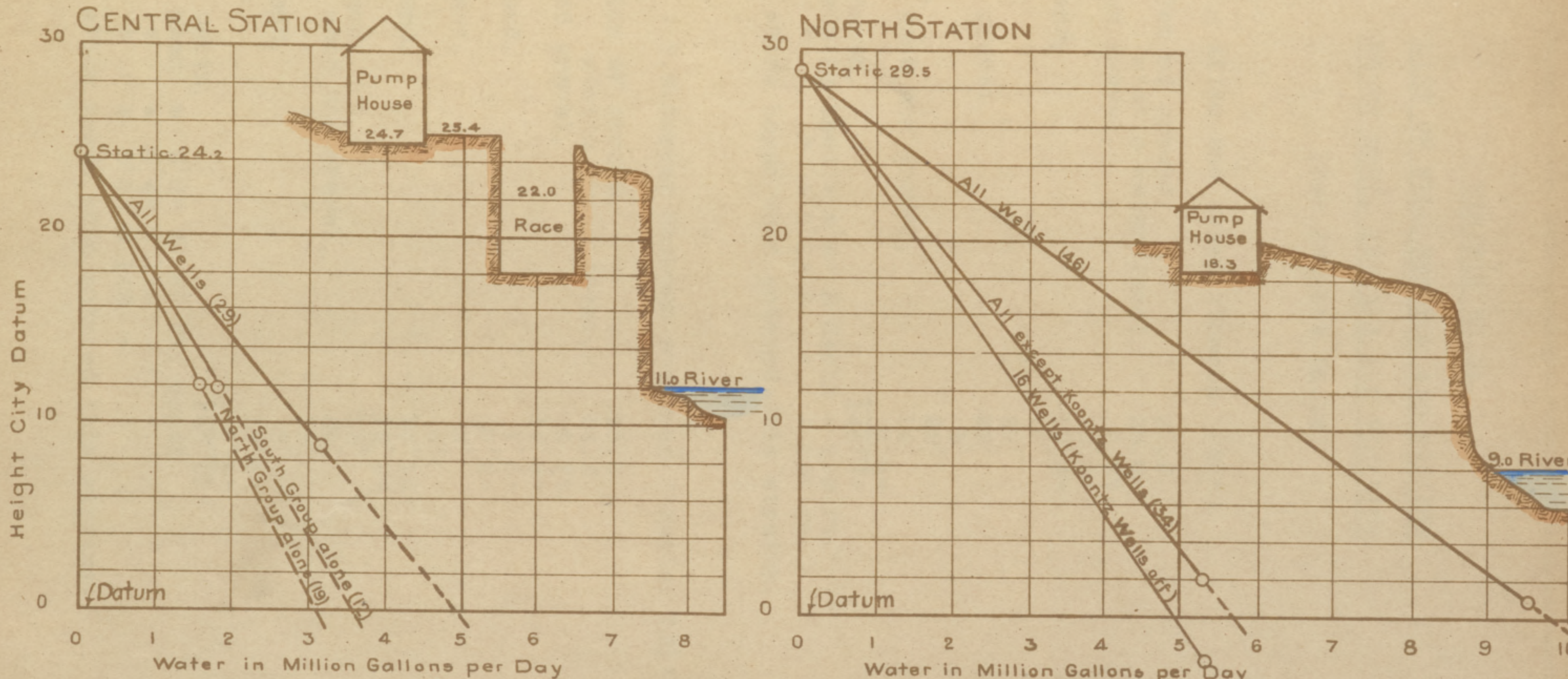


Diagram Showing
GOVERNING DATUM ELEVATIONS AND
TEST CAPACITIES OF PUMPING STATIONS
South Bend Water Wks.

To Accompany Thesis of
CHARLES BAKER BURDICK



CENTRAL STATION					
WATER BEARING STRATUM 20' to 30'					
14 - 4" Wells	sunk in	1886,	9' Screens	- Depth	114'
16 - 6" and 8"	"	1891,	9' "	- "	113' to 116'
6 - 10"	"	1906,	12' "	- "	98' to 110'
36 Total					

29 Wells in service during test

NORTH STATION					
WATER BEARING STRATUM 38'					
30 - 6" Wells	sunk in	1895,	10' Screens	- Depth	80' to 90'
4 - 10"	"	1906,	6' "	- "	80' " 90'
12 - 10"	"	1910,		"	98' " 102'
46 - Total					

All Wells in service during test

EXHIBIT NO.21.

LIST OF WELL RECORDS AND BORINGS.

SOUTH BEND, INDIANA, AND VICINITY.

(See Exhibit No.14).

TEST WELL NO.1. - Allen and Queen Streets. (2½").

Elevation of ground,	20.0
" static water level,	25.0
Sand and gravel,	7 ft.
Clay,	12'8"
Quicksand,	10'4"
Clay,	16'
Sand,	39'
* Coarse gravel,	22'
Sand,	3'
Gravel,	22'
Coarse sand and gravel,	14'
Shale,	0'9"
Depth,	146'9"

Water, static head + 4'6" @ depth - 102 ft.
" " " + 5'0" @ " - 126 ft.

*Flow began when entered this stratum.

TEST WELL NO.2. - N.E.Corner Sherman and Rose Streets. (2½").

Elevation of ground,	18.6
" static water level,	24.3
Sand and gravel,	8 ft.
Clay,	10'6"
Quicksand,	1'0"
Clay,	9'6"
Quicksand,	6'
Clay,	6'
Quicksand,	10'10"
Clay,	12'2"
Fine sand,	13'
* Coarse sand and gravel,	30'
" " " "	15'
Quicksand,	5'
Gravel,	18'6"
Shale,	0'4"
Depth,	145'10"

Static head + 6'4" @ 89 ft. depth.
" " + 6'4" @ 116 " "
" " + 5'9" @ 142 " "

*Flow began when entered this stratum.

EXHIBIT NO.21 (CONT'D)

TEST WELL NO.3. - Blaine Avenue near Tracks. (2½").

Elevation of ground,	24.1
" static water level,	29.8
Sand and gravel,	25 ft.
Clay,	8'
Quicksand,	5'
Clay,	8'6"
Fine sand,	39'6"
* Gravel,	57'11" +
Depth,	142'11"

Static head + 6'4" @ 99' depth.
" " + 6'4" @ 116' "
" " + 5'9" @ 142' "

* Flow started at 85 ft. depth.
\+ Struck something hard.

TEST WELL NO.4. - Angella Avenue (1500 ft. east of River).

Elevation of ground,	18.6
" static water level,	22.6
Sand and gravel,	12 ft.
Clay,	19'
Quicksand,	13'
Fine sand,	24'3"
* Sand and gravel,	50'0½"
Clay,	5'8½"
Shale,	1'
Depth,	125'

Static head + 4'0" @ 124' depth.

* Head first produced.

TEST WELL NO.5. - Corner Humboldt and Allen.

Elevation of ground,	49.2
" static water level,	30.2
Surface sand and gravel,	23 ft.
Struck boulder, 12'	
Another boulder, 23'	
Fine white sand,	19'
Clay,	35'
Medium white sand,	33'
* Gravel (W.W.)	41'11"
Shale at	151'11"

Water stood -18 to -20.

* Same as at water works.

EXHIBIT NO.21 (CONT'D)

TEST WELL NO.6. - Angella Avenue 225 ft. E.of Bridge.

Elevation of ground,	16.2
" static water level,	20.2
Top ground,	15 ft.
Sand and gravel,	6'
Quicksand,	5'
Clay,	21'
Quicksand,	46'
Fine sand,	13'
Coarse water-bearing gravel,	42'
Shale at 148'	
Depth,	148'

Static water + 4.0 @ 93' depth.
" " + 4.0 @ 148' "

TEST WELL NO.7. - Portage Park. (10").

Elevation of ground,	21.5
" static water level,	26.0

102' deep,
No record.

TEST WELL NO.8. - La Salle Park. (Jan.1911) Eddy St.& River.

Elevation of ground (approx.)	31
Static water at about river level	
Top soil,	10'
Blue clay,	40'
* Gravel, round coarse stones, fine sand, water,	10'
Clay,	50'
Quicksand, coarse sand and fine gravel,	20'
Clay,	20'
Shale at	150'

* Not same as at water works.

TEST WELL NO.9. - Eckman and LaFayette Streets. (10").

Elevation of ground (approx.)	95'
" static water level (approx.)	91'
Top ground,	20'
Clay,	40'
+ Coarse gravel,	10'
Quicksand,	20'
Clay,	20'

TEST WELL NO.9. - Eckman and LaFayette Streets, Cont'd.

* Good water-bearing gravel,	12'
Shale at	122'

+ Same as in LaSalle Park.
* Same as at Water Works.

TEST WELL NO.10. - Near Chapin and Warren Streets.

Elevation of ground, (approx.),	107'
" static water level,	78'
Surface soil,	2'
Sand, very fine,	23'
Clay, blue	10'
Gravel, coarse and fine sand,	4'
Gravel, mixed with clay,	14'
Gravel, round stones, fine sand,	39'
Fine gravel and sand (ditto),	28'
Light colored gravel and sand, (sand is fine and gritty)	7'
Light colored sand,	10'
Dark colored sand,	10'
(Coarse but little water) On shale.	147'
Shale,	34'10"
Depth,	182'

At depth of 95' water 40' from surface.
" " " 133' " 29' " "

TEST WELL NO.11. - Leeper Park.

Elevation of ground,	17.5
" static water level,	28.8
Top soil,	7'
Brown clay,	29'
Quicksand,	2'
Blue clay,	17'
Quicksand,	5'
Fine sand,	15'
Coarse angular sand and gravel,	25'
Finer " " " "	14'
No sample, but probably shale at depth.	114'

TEST WELL NO.14. - N. Pumping Station.

Elevation of ground	13.13
" static water level (approx.)	29
Top soil,	16'
Brown clay,	11'
Quicksand,	4'

TEST WELL NO.14.- N. Pumping Station, Cont'd.

Clay,	11'
Quicksand,	3'
Fine gray sand,	29'
Gravel and angular coarse sand,	10'
Pebbles and coarse sand,	12'
Coarse mixed sand,	14'
Finer " "	8'
Shale	3'
Depth,	121'

NO.18. - WELL AT CENTRAL STATION.

Elevation of ground (approx.)	25.4
" static water level,	24.2
Top soil,	14'
Clay,	59'
Packed sand,	9'
Gravel,	28' 10"
Depth,	110' 10"

NO.19. - WELL AT INDIANA & MICHIGAN ELECTRIC COMPANY, (1905),
9 - 8" wells.

Elevation of ground (approx.)	28.0
No record but disclosed same situation as regards depth and nature of strata as wells at Water Works, Central Station.	

NO.20.- WELL AT OLIVER HOTEL, (1903), Washington & Main Streets.

Elevation of ground,	51
" static water level,	32
Top gravel,	30'
Blue clay, quicksand, etc.,	103'
Gravel same as Water Works,	12'
Shale at	145'

NO.21.- WELL AT Y.M.C.A., (1907), Main and Wayne Streets.

Elevation of ground, (approx.)	51.7
" static water level,	39
Sand, fine, no pebbles, very little water, no clay,	100'
Shale at	100'

NO.22. - WELL AT STUDEBAKER FACTORY, Bronson & LaFayette Sts.(1908)

Elevation of ground,(approx.)	64
" static water level,	44
Top gravel,	60'
Blue clay,	30'
* Sand and gravel,	10'
Shale at depth	100'

* Substantially same as at Water Works except a little lighter color.

NO.23.- WELL AT OLIVER CHILLED PLOW WORKS, Chapin and Ford Streets.

Elevation of ground surface,(approx.)	62
" static water level, "	50

Open dug well 40' deep x 20' diameter.
All in heavy gravel and boulders mixed with a little round grained sand, about as coarse as Water Works sand.
Never went through this stuff.

NO.24.- WELL AT SINGER MFG.COMPANY, (1908).(Foundry) Division and Jackson Streets.

Elevation of ground,(approx.)	59
" static water level (approx.)	49
Top gravel fine (approx.),	40'
Thin vein of clay,	4'
Coarse sand, no gravel,	66'
Depth,	110'

NO.25.- WELL NEAR BECK'S LAKE.

Elevation of ground,(approx.)	51
" static water level,	57
Black dirt from surface of ground,	15'
Fine sand and gravel,	13'
Clay,	6'
Water sand,	28'
Coarse gravel,	21'
Sand and gravel,	19'
Fine sand,	27'
Depth,	129'

NO.26.- WELL AT SOUTH BEND BREWING COMPANY, (1907).

Elevation of ground (approx.),	54
" static water level,	49

Depth, 124 feet.
Lower 12' in material same as at Portage Park.
Does not penetrate gravel.
Went through clay about same as at Portage Park.
Vein of fine blue sand just above gravel not seen in any other well.

NO.27.- WELL AT MUESSEL BREWING COMPANY, (1908), Wilbur and Elmwood Streets.

Elevation of ground (approx.)	43
" static water level,	34

On bluffs.
2 wells just about the same as Portage Park; that is, water-bearing gravel is found at same depth datum.also head.

NO.28.- WELL AT SPRINGBROOK PARK.

Elevation of ground (approx.),	31
" static water level (approx.),	32

No record.

NO.29.- WELL AT CLEMENT STUDEBAKER ESTATE, (1911). E.Jefferson Street.

Elevation of ground (approx.),	78
Gravel and clay; shallow pockets of gravel in the clay; no water,	146'
Water-bearing gravel; coarse sand with small stones,	5'
Shale at	151'

NO.30.- WELL AT NOTRE DAME, (2" well).

Elevation of ground.	85.0
" static water level,	62.0
Surface,	20'
Blue clay,	20'
Light sand and quicksand,	103'
Medium sand and gravel.	8'
Depth,	151'

Does not penetrate to shale.

NO.31.- ST.MARY'S ACADEMY. 6" Well.

Elevation of ground,	10.2
" static water level,	12.0
Top soil,	10'
Blue clay,	20'
Quicksand,	50'
Gravel,	20'
Sand,	7'
Gravel,	8'
Blue clay,	4'
Water-bearing sand and gravel,	4'
Depth,	123'

NO.34.- WELL AT KAMM & SCHELLINGER BREWERY.

Elevation of ground (approx.),	35
Top soil and blue clay,	160'
* Gravel,	5'
Shale,	280'
Limestone, etc.	245'
Depth,	725'

* Static water level not determined at this point.

NO.35.- ONE OF THE FIVE TEST WELLS NEAR CORNER OF GEORGE ST. AND PROSPECT DRIVE, MISHAWAKA.

Elevation of ground (South Bend datum)	62
" static water level, "	55
Sand and gravel,	53'
Clay,	47'
Sand and gravel,	25'
Clay,	20'
Sand, gravel and stones,	75'
Clay,	4'
Sand,	75'
Stones,	3'
* Depth,	302'

* Not to shale.

NO.36.- TEST WELL AT INDIANA AVE.AND JOSEPH ST.,MISHAWAKA.

Elevation of ground (South Bend datum).	56
Gravel,	20'
Sand and gravel,	20'
Clay,	0' 6"
Sand,	21' 6"
Shale at	62'

NO.38.- TEST WELL AT POWER HOUSE, MISHAWAKA.

Elevation of ground (South Bend datum), 19

Sand and gravel,	25'
Clay,	7'
Clay and sand,	23'
Shale,	78'
Depth,	133'